Lower Willapa River
Fecal Coliform Bacteria
Total Maximum Daily Load Evaluation

Water Body Numbers WA-24-0020, WA-24-2010, and WA-24-2020

U.S. Environmental Protection Agency, Region 10
1200 Sixth Avenue
Seattle, Washington 98101

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Introduction

Background

The Willapa River basin drains into northeastern Willapa Bay, Washington. This report focuses on the lower Willapa River: the mainstem Willapa River and its tributaries from the Camp One Road bridge (downstream of Mill Creek) to the mouth of the river near Range Point in Willapa Bay. Ecology has listed the lower Willapa River under section 303(d) of the federal Clean Water Act as not meeting water quality standards for fecal coliform (FC) bacteria because of inadequate controls of point or nonpoint pollution sources.

Section 303(d) requires the states and U. S. Environmental Protection Agency (EPA) to establish "Total Maximum Daily Loads" (TMDLs) for all waterbodies on the Section 303(d) list. EPA must approve all TMDLs established by the State of Washington. A complete TMDL includes the following:

- Description of applicable water quality standards and relevant sources of pollutants;
- Technical analysis to determine the pollutant capacity of the waterbody;
- Allocations of pollutant loading to various sources;
- Margin of safety to account for scientific uncertainty;
- Method to account for seasonal variation;
- Monitoring plan and implementation strategy;
- Public participation in the TMDL development process.

In 1997, the Southwest Regional Office section of the Department of Ecology (Ecology) Water Quality Program conducted a Watershed Needs Assessment that included the Willapa River watershed (Ecology, 1997). The Willapa River was identified as a high priority for a TMDL technical study of FC bacteria problems. Ecology's Water Quality Program requested that the Environmental Assessment Program conduct the TMDL study, in partnership with state and local agencies and local citizens.

The principal local contact for Ecology during this study has been the North Pacific County Infrastructure Action Team (NPCIAT). The NPCIAT consists of the cities of Raymond and South Bend, Pacific County, the Port of Willapa Harbor, the Pacific Conservation District (CD), and many of the regional industries and resource groups.

This report describes the TMDL analysis for FC bacteria in the lower Willapa River. Previous documents produced under this study include the Quality Assurance Project Plan (QAPP) for this study (Pickett, 1998), and Data Summary Report (Pickett, 2000). The QAPP presents a review of historical data and a detailed description of the study plan. The Data Summary Report presents the data produced by field monitoring surveys, a summary of the Quality Assurance and Quality Control (QA/QC) analysis of the data, and an analysis of compliance with state water quality standards. The results of the TMDL analysis for FC bacteria in the upper Willapa River will be presented in a separate report.

Study Area

The Willapa River watershed, which includes the Willapa River and its tributaries, has a drainage area of about 262 square miles (680 km^2) and is located in Pacific County in southwestern Washington. The headwater elevations are approximately 6890 ft (2100 m). The lower Willapa River flows through the cities of Raymond and South Bend and empties into Willapa Bay. This lower Willapa River is tidally influenced from its mouth at Willapa Bay to approximately Camp One Road (a distance of about 14.5 miles). Major tributaries to lower Willapa River include South Fork Willapa River, Mill Creek, Wilson Creek, and Ellis Creek. South Fork Willapa River joins the Willapa River at about river mile (RM) 7.1 and Wilson Creek enters the Willapa River at RM 12.1. From the confluence with Mill Creek (RM 17.9) to its headwaters, the gradient of the Willapa River changes from moderate to steep which damps out the tidal influence. A map of the study area is presented in Figure 1.

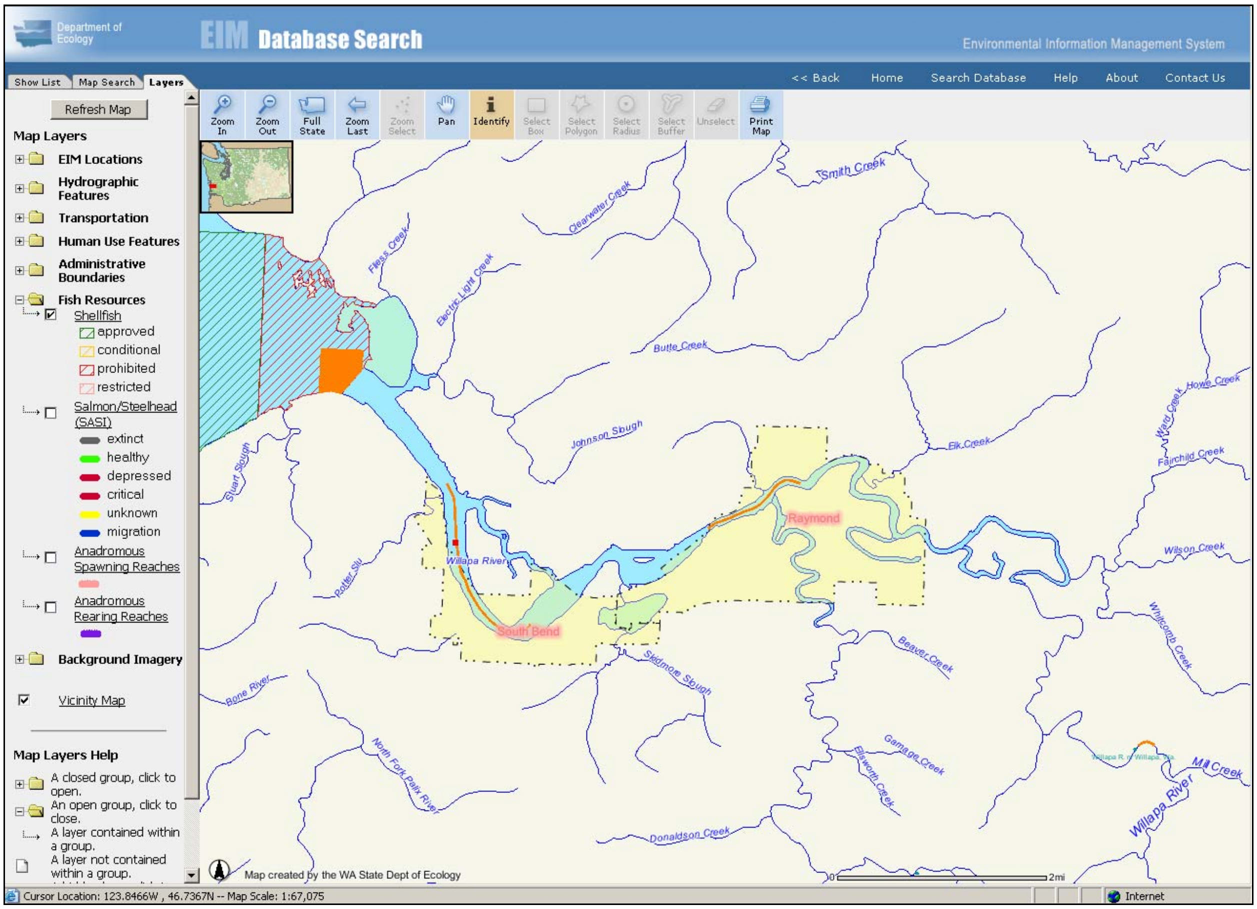

Figure 1. Lower Willapa River study area.

The principal land uses in the Willapa River watershed are forest (80%), agriculture (8%), and other (12%). The "other" land use category includes non-forest, developed land, open water, and wetlands. In the upper, steeper part of the watershed, the dominant land use is commercial forest, managed by a mixture of private owners as well as state and federal agencies. Where the slope decreases, a relatively wide valley floor develops, and the primary land cover changes to agriculture with dairy farms dominating the land use (Gove et al., 2001). According to the 2000

U.S. Census, the population of Pacific County is 20,984. The two major urban centers in the Willapa River watershed are the cities of Raymond and South Bend, both located in the lower Willapa River. Principal industries in these two cities are timber and seafood (mostly oysters). Agricultural land uses predominate in the river valley and silviculture is the main use throughout the rest of the basin. There are about a dozen large dairy operations in the basin, and numerous other livestock operations for beef and young stock.

Beginning at the upper end of the study area, the channel below Camp One Road is relatively narrow and winding, passing through agricultural area. Near the town of old Willapa at RM 12.0, Wilson Creek enters the river and the river channel becomes much wider. Below Wilson Creek the river passes through an area of numerous sloughs and tidal wetlands. The Highway 101 bridge over the Willapa River marks the upstream end of the maintained navigation channel and the beginning of the Raymond urban area.

The South Fork Willapa River enters the Willapa at RM 7.1. Tidal effects extend up the South Fork about 4.5 miles through an area of tidal wetlands and sloughs. The South Fork watershed represents about 20% of the total watershed area. However, summer base flows in the South Fork are actually slightly higher than in the mainstem Willapa River above the South Fork.

The mouth of the South Fork is in the industrial area of Raymond. The Weyerhaeuser lumber mill lies on the north bank, a Pacific Hardwoods mill on Port lands on the south bank, the Port docks just downstream of the mouth, and the Raymond municipal wastewater treatment plant (WWTP) across the mainstem from the mouth. The Ecology marine ambient monitoring site WPA001 is just off the Port docks.

From the South Fork to the Bay, the Willapa River is relatively wide, except for an area called “The Narrows” between Raymond and South Bend. Just below the narrows is a small industrial area with a Pacific Hardwoods mill and East Point Seafoods. The two other fish processors in South Bend are South Bend Packers near the center of town and Coast Seafoods at the west end of town. The South Bend WWTP sits between the river and Mailboat Slough across from the city. The Mailboat slough area floods during high tides, which limits access to the South Bend WWTP. The mouth of the Willapa River is considered to be near the “Green 33” navigation aid and Johnson Slough.

Flows in Willapa River have been monitored since 1947 (continuously since 1961) at USGS station 12013500 (Willapa River near Willapa, WA), which has a contributing area of about 130 square miles. Mean monthly flow is highest in December (1,509 cfs) and lowest in August (48.7 cfs). The mean annual flow at the USGS station is 636 cfs.

The Willapa River near Raymond, Washington, has a history of low dissolved oxygen and is included on the Department of Ecology’s 303(d) list of impaired waters. A computer model of the lower Willapa River was developed by the Department of Ecology using the EPA DYNHYD5 and EUTRO5 models (referred to herein as the “original” WASP model). The model computational domain includes the tidal Willapa River from its mouth at Willapa Bay (Range Point) and continuing upstream for a distance of about 17.8 miles as well as the South Fork from its confluence with the Willapa River and continuing upstream for a distance of about

5.0 miles. The DYNHYD model was applied to the lower Willapa to supply tidal-varying hydrodynamics to the EUTRO water quality model.

A consultant for the North Pacific County Infrastructure Action Team (NPCIAT) reviewed the draft WASP model and produced a review document in July 2001. NPCIAT's consultant had a number of comments on the WASP model including (1) the ratio of ultimate CBOD to 5-day CBOD, (2) phytoplankton productivity, (3) salinity loadings from point sources, (4) the affect of salinity and productivity assumptions on the TMDL results, (5) tracer simulations and dispersion coefficients, and (6) sensitivity to kinetic rate constants.

An updated WASP model has been developed based on the original WASP model. Updated versions of the DYNHYD (DYN51t) and WASP (WASP51t) code were used for this effort (Tetra Tech, 1995, 2002). WASP51t includes four additional state variables not found in the EPA version of WASP: two bacteria state variables, a salinity state variable, and a TSS state variable.

Water Quality Standards

The Surface Water Quality Standards for the State of Washington are described in Chapter 173-201A WAC. The Willapa River and its tributaries in the study area are subject to Class A fresh water standards, with the exception of the downstream 1.8 miles of the study area, which is subject to Class A marine standards. According to the WQS regulations, the boundary between marine and freshwater standards occurs at Mailboat Slough navigation light (RM 1.8). Water Quality Standards for fecal coliform bacteria are as follows:

> Class A Freshwater: Fecal coliform organism levels shall both not exceed a geometric mean value of 100 colonies/100 mL and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 200 colonies/100 mL.
>
> Class A Marine: Fecal coliform organism levels shall both not exceed a geometric mean value of 14 colonies/100 mL and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 43 colonies/100 mL.

Water bodies that do not meet the water quality standards despite the presence of technology-based pollutant controls are required by Section 303(d) of the Clean Water Act to be placed on a list of water-quality limited water bodies (Ecology, 1996). Waterbodies in the lower Willapa River study area listed in 1998 for exceedance of the fecal coliform bacteria water quality standard are shown in Table 2.

If water quality standards are not being met or are threatened by existing pollutant sources, then a Total Daily Maximum Load (TMDL) may be established to regulate acceptable pollutant loads, as required under Section 303(d) of the Federal Clean Water Act. The combined effects of various sources in the basin need to be evaluated as part of the TMDL technical study, to determine the best strategy to establish a TMDL and protect beneficial uses for the basin. The TMDL may be apportioned between point sources (waste load allocations or WLAs) if present, and nonpoint or background sources (load allocations or LAs). The allocations (WLAs and LAs) may be implemented through NPDES permits, state waste discharge permits, grant projects, watershed action plans, and other nonpoint source control activities.

Table 1. Waterbodies in Lower Willapa River on 303(d) list for FC bacteria impairment.

Listing ID	Name	Waterbody ID	RM lower	RM upper
6688	Willapa River near South Bend	YN05JR	1.60	2.35
10000	Willapa River near Raymond	YN05JR	7.60	7.89
10001	Willapa River near Willapa	YN05JR	13.93	14.07
10002	Willapa River downstream of Mill Creek	YN05JR	17.49	17.97

Pollution Sources

There are five permitted NPDES dischargers that discharge to the Lower Willapa River in the study area and have the potential to affect FC bacteria (see Table 2). Two of the discharges are NPDES permitted municipal wastewater treatment plants (WWTPs) and the other three are seafood-processing facilities.

A number of potential nonpoint pollutant sources exist in the Lower Willapa River study area. Urban stormwater reaches the Willapa River via overland runoff and direct stormwater discharges. Agricultural practices may be a source of nonpoint pollutants that reach the Willapa River through overland flow to tributary streams, or direct contact from farm animals. Most of the farmland in the study area lies in the wide river valleys adjacent to the Willapa River and its tributaries. At least one cattle farm operates in the Lower Willapa River basin with a pasture that experiences flooding during high tide. This pasture has been identified as a potential source of FC bacteria in the Lower Willapa River. Failing or inadequate septic systems may also represent another potential pollutant source. Wildlife and waterfowl represent another potential source of FC bacteria in the study area.

Table 2. NPDES permitted facilities discharging to Lower Willapa River.

Facility Name	NPDES ID	Permit Flow (mgd)	Permit FC Bacteria (cfu/100 mL)	Max. FC reported 1998-2002 (cfu/100 mL)	WASP segment
Coast Seafood	WA0002186	0.099	*	44,000	11
City of South Bend WWTP	WA0037591	0.375	200	532	12
South Bend Packers	WA0040941	0.010	*	1,600	13
East Point Seafood	WA0001104	0.320	*	2,200	14
City of Raymond WWTP	WA0023329	1.500	200	502	24

* = no permit limit, facility is required to monitor only

The seafood processors screen their wastewater and discharge directly to the Willapa River. Coast Seafoods processes oysters and uses a mixture of saline river water for shell washing and city water for processing. East Point seafood processes a variety of products, including fish, crab and shrimp, and uses city water for processing. South Bend Packers mostly processes fish filets and sometimes processes oysters.

Possible nonpoint sources of FC bacteria in the basin include:

- On-site septic systems;
- Municipal stormwater runoff;
- Livestock; and
- Natural background sources including wildlife and waterfowl.

Since most of the lower Willapa River is either tidal wetlands or behind levees, nonpoint sources are mostly assumed to reach the River through tributary creeks, sloughs, and drains. Municipal stormwater FC bacteria loads were estimated for Raymond and South Bend by delineating these two municipalities into subbasins and calculating the daily storm runoff volumes (*Q*) for each subbasin using the rational method ($Q=CiA$) where *C* is the runoff coefficient for urban land use (assumed to be 0.5), *i* is the daily rainfall, and *A* is the subbasin area. Typical FC bacteria event mean concentration (EMC) for various urban land uses ranges from 6,900-53,000 cfu/100 mL (Baird et al., 1996). For this study, the FC bacteria EMCs for urban stormwater runoff were assumed to be variable, ranging from 1,500 to 20,000 cfu/100mL depending on the daily rainfall (see Figure 2).

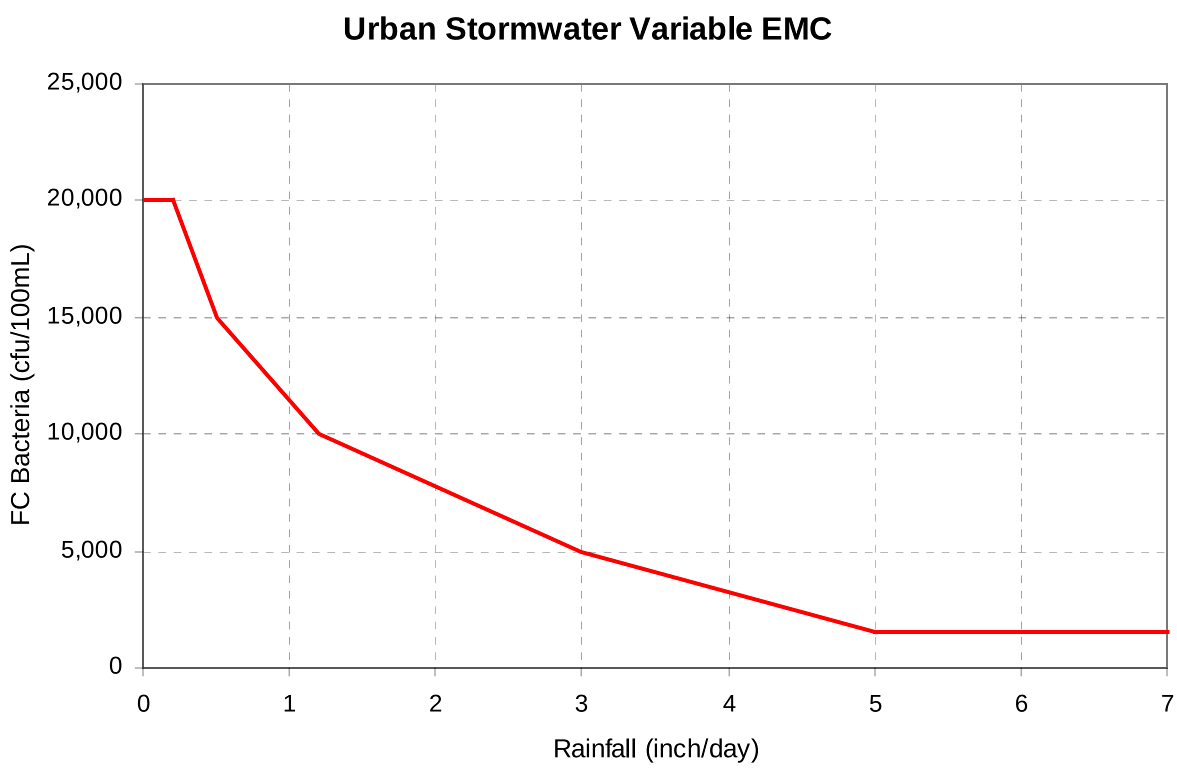

Figure 2. FC bacteria event mean concentration as a function of daily rainfall.

Project Objectives

The major objectives of the project are as follows:

- Conduct water quality monitoring surveys for physical, chemical, and biological parameters to characterize environmental conditions that affect FC bacteria levels in the Willapa River; and to use the monitoring data to support the calibration and verification of a hydrodynamic and water quality computer model for FC bacteria.

- Develop a water quality computer model for FC bacteria, using GIS, a dynamic computer model, and other analytical tools.

- Use the FC bacteria computer model to evaluate the environmental conditions that control FC bacteria levels in the Lower Willapa River; assess the relative levels of FC bacteria loading from sources along the Willapa River and from the river's watershed; and determine the capacity of the river to assimilate FC bacteria loading from point and nonpoint sources and meet water quality criteria for FC bacteria.

- Evaluate and recommend a TMDL strategy, possibly including pollutant load allocations for various sources, to meet water quality standards for FC bacteria and protect beneficial uses in the Lower Willapa River.

Water quality monitoring results were reported in the Data Summary Report (Pickett, 2000). This report documents the results that address the other three objectives.

Methods

Methods for field monitoring surveys were described in detail in the QAPP and Data Summary Report (Pickett, 1998; 2000).

The lower Willapa River study area was modeled using the Water Quality Analysis Simulation Program, or WASP5 (Ambrose, *et al.*, 1993). The EUTRO5 kinetic sub-model of WASP5 and the DYNHYD hydrodynamics program were used for this analysis. The EUTRO5 simulation links to an associated DYNHYD hydrodynamic file where it reads the necessary transport information (i.e., flows and volumes).

The overall modeling strategy was to select a target period to be modeled (the 1998 survey dates or the seasonal period of critical flow and tidal conditions), and then specify input conditions corresponding with those dates. The tidal simulation was run continuously for 247 days beginning on April 1, 1998 (day 91), and continuing until December 24, 1998 (day 358). Dynamic model inputs were used for tributary and point sources as well as for the tidal boundary conditions.

Hydrodynamic Model Inputs

DYNHYD uses a "link-node" finite-difference method to solve the equations of state for water flow and volume. This method overlays two sets of networks: links, or "channels", that convey water and conserve energy and momentum; and nodes, or "junctions", that store water and conserve mass. For the DYNHYD model, the lower Willapa River was divided into 67 channels and junctions. Figure A-1 (Appendix A) shows the junctions used in the lower Willapa River model. There are 26 junctions in the mainstem below South Fork, 13 junctions in the South Fork, and 28 junctions in the mainstem above the South Fork. Junctions have also been included for several of the major side-channels such as Mailboat Slough and Ellis Slough. Channels (not shown in Figure A-1) connect each pair of adjacent junctions.

The downstream boundary was set at Range Point at the edge of Willapa Bay. This boundary was chosen because a hydrodynamic model of Willapa Bay (Kraus, 2000) indicated that at this location the one-dimensional circulation patterns of the River transition to the two-dimensional circulation of Willapa Bay. Modeling farther into the Bay would require a greater field survey effort to gather additional hydrodynamic circulation and tidal data to adequately configure and calibrate the DYNHYD model.

The two upstream boundaries of the model are located at the USGS Willapa River near the USGS stream flow gage (12013500), and at the City of Raymond Water Intake on the South Fork Willapa River off Golf Course Road.

One of the DYNHYD input files (for the September 1998 calibration) is shown in Appendix C. Model input parameters are described below in order of their occurrence in the input file:

Data Groups A, B, and C: Program, Printout, and Summary Control. The model was run for 249 simulation days (from day 91 to day 360). This period covered the entire calibration and verification period (April 1 to December 26, 1998). A one-second computational interval was necessary to achieve stability in the upper river channels due to their relatively steep gradients. A total of 120 hydraulic time steps per water quality time step were chosen to ensure numerical stability and allow for reasonable water quality run times.

Data Groups D and E: Junction and Channel Data. Junction surface elevation, bottom elevation, and surface area; and channel length, width, and depth were determined from bathymetry cross-section data or from topographic or navigation maps. Bathymetry for the navigation channel between the Port docks in Raymond and Willapa Bay was obtained from the Army Corps of Engineers. These data were combined with map data and analyzed with ArcView and Spatial Analyst® (ESRI, 1999) to determine surface area and volume at mean lower low water (MLLW), mean tide, and mean higher high water (MHHW).

In the South Fork and mainstem above the Port docks, cross-section depths were measured with sonar and channel widths were measured with a laser range finder. The cross-sections were digitized to determine average depth and width. Bottom elevations were determined by comparing measured depth to published tide heights at the time of measurement (NSI, 1996). For areas where no survey data were available, bottom elevations were estimated from NOAA navigational charts or from USGS topographic maps. The bottom elevations at the upstream junctions in both the Willapa River and South Fork were estimated to be +12.6 ft NGVD (+17.01 ft MLLW or +5.18 m MLLW) based on elevation contours from USGS topographic maps. All model bottom elevations were adjusted to the MLLW datum at Toke Point based on available NOAA tidal datum information shown in Table 3, i.e., the NGVD elevation contours from USGS topographic maps were adjusted to MLLW at Toke Point by adding 4.41 ft (1.34 m).

Table 3. Tidal datum information at Toke Point, Willapa Bay.

```
Station ID: 9440910                                 PUBLICATION DATE:  02/10/1988
Name:       TOKE POINT, WILLAPA BAY, WASHINGTON     NOAA Chart: 18504
Latitude: 46d 42.5' N                               Longitude: 123d 57.9' W
USGS Quad:  BAY CENTER
                            T I D A L   D A T U M S

Tidal datums at TOKE POINT, WILLAPA BAY based on:
     LENGTH OF SERIES:      9 YEARS
     TIME PERIOD:           1977-1985
     TIDAL EPOCH:           1960-1978
     CONTROL TIDE STATION:  9439040 ASTORIA, OR

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in FEET:
     HIGHEST OBSERVED WATER LEVEL (11/14/1981)    =  14.38
     MEAN HIGHER HIGH WATER (MHHW)                =   8.85
     MEAN HIGH WATER (MHW)                        =   8.11
     MEAN TIDE LEVEL (MTL)                        =   4.72
   * NATIONAL GEODETIC VERTICAL DATUM-1929 (NGVD) =   4.41
     MEAN LOW WATER (MLW)                         =   1.33
     MEAN LOWER LOW WATER (MLLW)                  =   0.00
     LOWEST  OBSERVED WATER LEVEL (12/19/1983)    =  -3.84

   * NGVD reference based on publication Quad 13 WASH, 1972, and NOS leveling of 1986
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Bathymetric analysis results from these various methods were combined in a spreadsheet to calculate model input data. Junction bottom elevations were decreased slightly to ensure model stability during extreme low tides. Values of the Manning’s roughness coefficient were estimated from channel conditions and adjusted through calibration. Once the model was calibrated, the junction and channel dimensions were kept constant for all subsequent simulations.

Data Group F: Inflow Data. For calibration and verification, inflows at the upstream boundaries were determined from direct flow measurements by USGS or Ecology. Regressions were developed to predict upstream boundary flows from USGS flows, for use when no direct flow measurements were available.

A GIS-based method was used to estimate daily stream flows for the peripheral ungaged tributaries. It was also employed to help reconstruct stream flows in some of the larger tributaries for the late November through December 1998 period when stream flow became too great for many of the gages to measure.

The GIS analysis uses watershed area, average annual precipitation information, the digital elevation model (DEM) for the basin, and one continuous gage to estimate stream flow at points throughout the watershed. This analysis is based on methods developed by the University of Texas Center for Research in Water Resources and described on their website (Olivera, 1996). It was further developed at Ecology to accumulate precipitation across the landscape.

Briefly, watershed area above each of the sample sites was calculated using the grid-based Spatial Analyst extension to ESRI Arcview (ESRI, 1999). These areas were then weighted using an average annual precipitation grid. The precipitation-weighted area above the continuous gage is calculated and becomes the value representing 100% of the stream flow (the denominator value). In this case, the USGS gage near the town of Willapa provided the continuous gage. The weighted area above each desired tributary inflow was calculated and divided by the denominator to produce the fraction of the stream flow delivered to that point. The daily continuous flow record at the USGS gage was multiplied by the appropriate fraction to produce a hydrograph for each of the sub-basin tributaries. Hydrologists have used sub-watershed area to estimate flow for many years (e.g., a subwatershed with an area that is 10% of the total watershed, should have 10% of the flow). The GIS method automates the area calculation and allows subwatersheds with heavier precipitation to receive a larger proportion of the flow. Often precipitation varies dramatically across a watershed, especially at the higher elevations.

Ecology used this method to help explain streamflow in the Chehalis (Pelletier, 2000) and Teanaway (Stohr, 2000) technical studies. This method of estimating daily stream flow is expected to be most successful in basins that do not use extensive water withdrawals and that have a continuous stream gage in the basin for calibration. The method assumes that soil types and other parameters affecting delivery of precipitation to stream flow are similar across watershed. These conditions are met in the Willapa River basin.

Flows calculated with the GIS-derived fraction were checked against other gaged tributaries and the method produced reasonably good results. Tributary flows were summed for each segment, and input flows were only used for segments that represented at least 0.1% of total inflow or were possible significant pollutant sources such as the lumber mills.

There are five NPDES discharges in the Willapa River model with flow rates ranging from 0.091 mgd to 1.0 mgd (see Table 2). The model also includes 33 tributary flow inputs. Since there was only one long-term flow gage in the Willapa River study area, time-varying flows at the tributaries were estimated using the USGS stream gage at Willapa (#12013500) and the flow ratios discussed previously. The flow rates for the three largest tributaries were based on regression to the USGS gage:

Wilson Creek (junction 56):	*Q = 0.1434 + 0.2248 * Qusgs*
South Fork Willapa River (junction 39):	*Q = 0.5678 + 0.3150 * Qusgs*
Willapa River (junction 67):	*Q = 0.0000 + 1.0000 * Qusgs*

The flow rates for the junctions where the smaller tributaries enter the Willapa River were estimated using the following equation:

*Qjunc = Ratio * Qusgs*

where *Qusgs* is the flow (cfs) at the USGS stream gage 12013500 and *Ratio* is given in Table 4.

Table 4. Flow estimates for tributaries in Willapa River model (Qjunc = Ratio * Qusgs)

DYNHYD Junction	Ratio	DYNHYD Junction	Ratio	DYNHYD Junction	Ratio
3	0.042	21	0.003	42	0.046
7	0.013	22	0.004	46	0.004
11	0.003	24	0.006	49	0.007
12	0.018	25	0.001	51	0.003
13	0.003	26	0.018	53	0.006
14	0.003	31	0.003	60	0.006
15	0.004	32	0.009	61	0.004
16	0.009	35	0.007	62	0.005
18	0.007	37	0.004	63	0.013
20	0.036	41	0.004	66	0.003

For the TMDL analysis, critical low flows were determined for three seasons: spring (April through June), summer (July through September), and fall (October through December). These seasons were selected as part of the analysis of seasonal variation during project planning (Pickett, 1998). The risk of DO standards being exceeded in winter was found to be negligible. Seasonal 7Q10 low flows (seven-day annual low flow with a ten-year average recurrence interval) were calculated for each season for the USGS station in the Willapa River near Willapa. Tributary flows were then calculated using the GIS-based flow fractions or regressions.

Data Group G: Seaward Boundary Data. Tide information for the seaward boundary of the model was obtained from the NOAA harmonic prediction station at Toke Point in Willapa Bay. Two tide gages were also installed during the period September 24-26, 2002, at DYNHYD segment 25 (Port of Willapa Harbor at the South Fork confluence near Raymond) and segment 44 at the mouth of Ellis Slough (CEG, 2002). The 2002 tide gage data and additional bathymetric measurements were used to make adjustments to model geometry and bottom roughness in order to achieve the proper tide elevation difference observed between the two gage locations. The observed elevation difference is compared with the model results for the original geometry and the final (modified) geometry in Figure 3. It is obvious the modified geometry provides much better agreement with the observed tidal elevation difference than the original geometry.

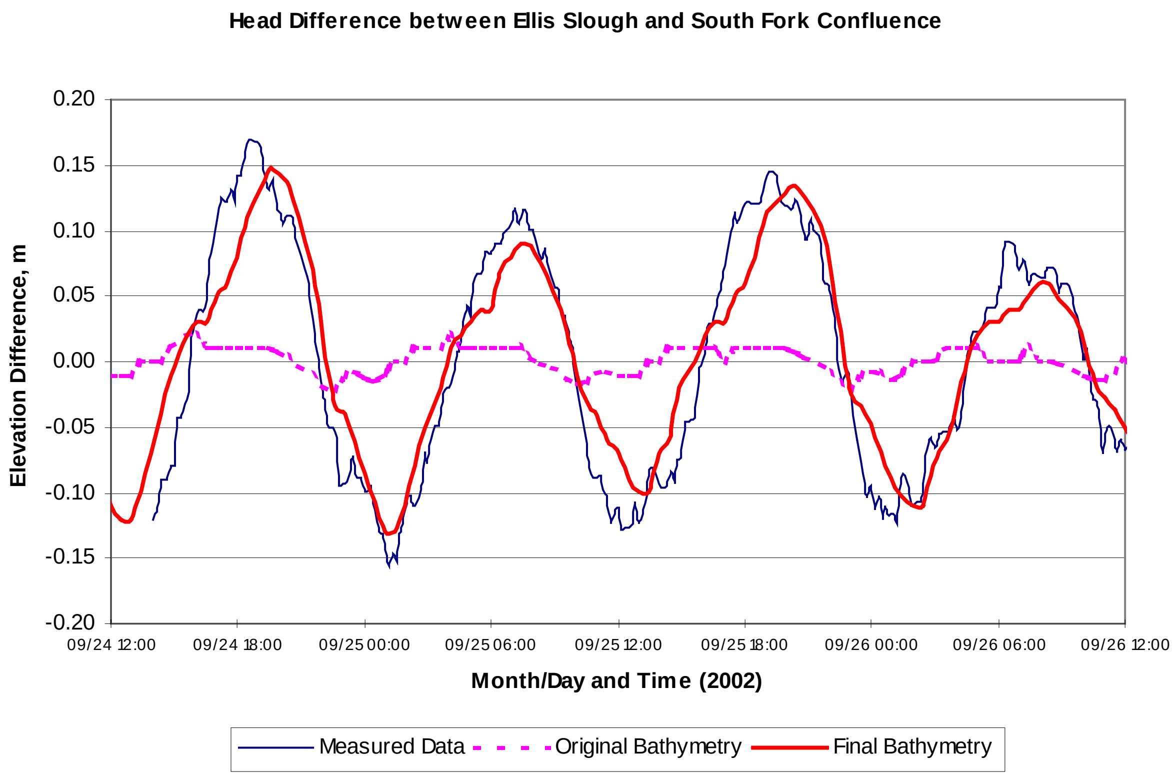

Figure 3. Head difference between Ellis Slough and confluence of South Fork.

Toke Point tides and model bottom elevations were adjusted to a common datum (MLLW) for this study (see Table 3). The input data set consisted of 249 days of high and low tides, which DYNHYD fit to half sine curves, covering the period April 1 to December 26, 1998.

Data Groups H, I, and J: Other Data. Options for wind, precipitation, and evaporation input data were not used for this simulation.

Water Quality Model Inputs

To begin calibration of the water quality model and aid in the calibration of the hydrodynamic model, EUTRO5 was used to simulate salinity and a dye tracer in the lower Willapa River. A modified version of WASP5 developed by Tetra Tech (2002) was used that includes salinity and bacteria as additional state variables. The dye tracer was simulated using the state variable for bacteria, which includes a first-order decay term.

The model segments for EUTRO5 line up with the DYNHYD junctions, except that boundary channels that are numbered in DYNHYD are designated with “0” in EUTRO5. Looking at Figure A-2, junctions 1, 39, and 67 in DYNHYD are boundaries in EUTRO5, and the water quality segments are renumbered, resulting in a total of 64 surface water quality segments.

After calibration of the hydrodynamic transport and dispersion using the salinity and dye tracer simulations, the FC bacteria water quality model was calibrated. EUTRO5 was run with only the salinity and bacteria state variables activated. In most cases literature values for model parameters were found in EPA (1985). The EUTRO5 input file used for calibration is presented in Appendix D. Model input parameters are described below in order of their occurrence in the input file.

<u>Data Group A: Simulation Control.</u> The Willapa River water quality model uses 67 model segments: 64 segments representing the water column and 3 segments representing the benthos. The model is run from day 91 (April 1, 1998) to day 358 (December 24, 1998), or a period of 247 days. The water quality model time step is 120 seconds (0.0013889 days). Model results are saved to the output file at 2.0-hour intervals (0.083333 days). A predominately backward difference option was used (i.e., the advection factor ADFA= 0.1).

<u>Data Groups B and C: Exchange Coefficients and Segment Volumes.</u> Segment volumes and characteristic areas and lengths were calculated from the DYNHYD junction and channel geometries. Initial exchange (dispersion) coefficients were selected from literature values and then adjusted during salinity and dye tracer calibration. Following salinity and dye tracer calibration, the exchange coefficients and segment volumes were kept constant during all subsequent simulations.

<u>Data Group D: Flows.</u> This data group provides for the advective transport flows used by the water quality model. These flow characteristics are provided by the hydrodynamic model, DYNHYD, through the hydrodynamic file *dyn98cal.hyd*.

<u>Data Group E: Boundary Conditions.</u> The model uses three boundary conditions: the seaward boundary at Range Point, and freshwater upstream boundaries at South Fork Willapa River, and the mainstem upper Willapa River. For calibration and verification, boundary conditions were developed from the time-series values of data from each field survey. For salinity, data from several sources were available: datalogger recordings, field profiles (from Ecology and Cosmopolitan Engineering [1999a]), and laboratory analysis. Salinity calibration indicated that an average value of 26.0 ppt was appropriate to use for the seaward boundary value. For the South Fork boundary, salinity was set to 0.01 ppt, and for the upper Willapa River boundary, salinity was set to 0.03 ppt based on field data.

Time-varying FC bacteria concentrations were used for the seaward and upstream boundary conditions based on field data. At the seaward boundary the FC concentrations varied throughout the 1998 simulation period from a low of 1 cfu/100mL to a high of 12 cfu/100mL. At the South Fork boundary, FC concentrations varied from 2 to 185 cfu/100mL. At the upper Willapa River boundary, FC concentrations varied from 4 to 330 cfu/100mL.

<u>Data Group F: Waste Loads.</u> Waste loads were specified for point source loading from two municipal wastewater treatment plants and three seafood processors, and for nonpoint source and background tributary loading. Tributary loading, including runoff from the lumber mills, was calculated from input flows (determined for DYNHYD inputs) and concentrations measured during surveys. Unmonitored tributaries were assigned concentrations from neighboring monitored tributaries. Point source loading for calibration and verification was calculated from measured flows and concentrations during the surveys. Loading from tidal inundation of pastureland in the vicinity of Mailboat Slough was calculated based on the estimated number of cows using the pasture during different months of the year. Estimates of wildlife and waterfowl bacteria loads were made assuming that the FC bacteria load equivalent to one duck would be deposited into each model segment each day (i.e., 2.5E+09 cfu/day as reported in EPA, 2001).

For critical conditions modeling, point source loading was developed from critical design flows and contaminant concentrations. Gray and Osborne (2000) provided municipal flows and ammonia concentrations. Seafood processor flows and loading were determined from NPDES permit fact sheet information, the EPA development document for the seafood processing industry, and historical Discharge Monitoring Reports. Nonpoint source loading, including the lumber mills, was set at the highest season concentrations for critical conditions, and the lowest seasonal concentrations for natural conditions.

<u>Data Group G: Water Body Parameters.</u> The parameters in this group represent the spatially variable characteristics of the water body. Two water body parameters were necessary for the FC bacteria model simulations: TMPFN, which identified the appropriate water temperature time function to assign to each model segment, and TMPSG, which is a multiplication factor applied to the temperature time function (TMPSG was set to 1.0 for all segments).

<u>Data Group H: Kinetic Model Rate Constants.</u> Two constants are specified in this data group: *salcvt*=1.0 is used to convert units of salinity specified in Data Group E to g/L (i.e., ppt). Also specified in this data group is the bacteria decay rate (KBAC1). A first-order bacteria decay coefficient of 0.2/day was determined based on typical literature values (EPA, 2001) and the model calculated adjustments to the decay rate for salinity and temperature based on a modified Mancini equation (i.e., constant BACSW1=3).

<u>Data Group I: Kinetic Time Functions.</u> Four kinetic time functions were specified for the Willapa River FC bacteria model to define water temperature for different reaches of the river system. The water temperatures were used to adjust the bacteria decay rate.

<u>Data Group J: Initial Conditions.</u> Initial starting values for salinity and FC bacteria were specified for each model segment in this data group.

Total Maximum Daily Load Analysis

Model Calibration Results

A summary of calibration tidal height differences, salinity, and dye tracer dilutions can be found in CEG (2003). The original hydrodynamic model developed by Ecology (Pickett, 2000) was unable to accurately represent the dampening of tides in the upstream reaches of the mainstem Willapa River and South Fork Willapa River. This limitation was overcome by use of revised geometry, roughness, and bottom elevations in the updated model. Overall the hydrodynamic model produced reasonable results, and model results compared favorably to observed conditions.

The hydrodynamic and water quality models were executed for the entire 1998 period for which observed FC bacteria data were monitored (i.e., April 1 to December 24). Qualitative assessment of model calibration was accomplished by visual inspection of time series of model-data graphics at various monitoring locations for the geometric mean and 90th percentile statistical measures. These model-data figures are presented in Appendix A at seven monitoring stations (see Figures A-03 to A-09).

Calibration results were evaluated to understand the sources of variability in the model. A simple sensitivity analysis was also conducted to determine the major factors contributing to model results. A rigorous sensitivity or error analysis was not conducted due to the complexity of the model as well as time and budget limitations. There are several possible factors that contribute to model variability:

- The sensitivity analysis showed that during the spring and summer months when tributary flows were low, FC bacteria levels in the vicinity of Mailboat Slough were sensitive to changes in loading from the cow pasture that adjoins the river in that location. The impact of the cow pasture FC bacteria loads was not as evident during the fall months (November and December) when tributary flows and loads were higher.
- Changes in municipal stormwater loads has a noticeable impact on FC bacteria levels in the lower 10 miles of Willapa River during both the summer and fall seasons.
- Changing the loads of the Raymond and South Bend WWTPs as well as the three seafood-processing plants had little impact on the FC bacteria levels in the lower Willapa River.
- Tributary flows and loads had the most significant impact on overall FC bacteria concentrations in the lower Willapa River.
- Little is known regarding the FC bacteria loading from wildlife and waterfowl. A constant nominal load of 2.5E+09 cfu/day was added to each WASP model segment in the lower Willapa River below Ellis Slough. This corresponded to approximately the daily load expected from one duck (EPA, 2001) to each model segment.

The limitations of the model described above may explain the differences found between calibration and verification. Overall the model predicted the geometric mean and 90th percentile FC bacteria concentrations, capturing the timing and geographic distribution of maximum values. The model predicted high FC bacteria levels for some times and locations and low FC bacteria levels at other times, showing no substantial bias overall. If sources of variability are given due consideration, the model can be used to develop reasonable TMDL allocation scenarios.

TMDL Allocation Scenarios

Following calibration, the model was run for a period that included critical seasonal environmental conditions as well as estimated maximum pollutant loading levels from point sources and nonpoint sources. Since the model was calibrated using FC bacteria data from 1998, that year was also selected for use in the TMDL allocation scenario analysis. For the TMDL allocation simulations, the model was run for the period April 1 to December 24, 1998, which includes a spring-summer period (April 1 to October 31) characterized by low tributary flows and a fall period (November 1 to December 24) characterized by relatively high tributary flows.

Setting TMDL allocations for the Willapa River may involve a complex set of trade-offs. The final TMDL and implementation strategy chosen will depend on many different engineering, economic, and political factors. These will have to be resolved during the initial implementation process. The TMDL allocation scenarios developed in this report provide examples of possible TMDLs using the Willapa River water quality model. The baseline condition and five allocation scenarios were simulated using the model. TMDL allocations were developed for the spring-summer period (April-October) and the fall period (November-December). A description of the alternative scenarios is provided in Table 5.

Allocations were made to six categories of FC bacteria sources: wastewater treatment plants, the seafood processing plants, the upstream Willapa River boundary, other peripheral tributaries, the cow pasture in the vicinity of Mailboat Slough, and municipal stormwater runoff. For the baseline conditions, the Raymond and South Bend WWTPs as well as the seafood-processing plants were set to the permitted flow rates and the worse case FC concentration measured during the period 1998-2002 (see Table 2). Bacteria loads for the Willapa River upstream boundary and the other tributaries were calculated using the flows and FC concentrations from the 1998 calibration. The loading from the cow pasture was estimated based on the presence of between 2 and 50 cows at various times of the year. The FC bacteria load for a cow was estimated as 1.0E+11 cfu/day (EPA, 2001). Municipal stormwater loads were calculated based on daily rainfall and a variable event mean concentration that was a function of rainfall.

Model results for the different allocation runs are presented as longitudinal transect plots as well as time-series graphics for the geometric mean and 90th percentile statistics. The critical location for compliance with the water quality standard is the lower 1.8 miles of Willapa River, which is subject to the more stringent marine Class A standard. The spring-summer transect allocation results (Figures B-01 and B-02) indicate that allocation alternative 3 satisfies both the geometric mean and 90th percentile standard. For the fall period, however, the more stringent allocation alternative 6 (Figures B-03 and B-04) is necessary to satisfy the geometric mean and 90th percentile standard in the marine waters of the lower Willapa River downstream of river mile 1.8. According to the shellfish areas shown in Figure 1, the lower 1.8 miles of Willapa River is not designated as a shellfish use area. Therefore, it is uncertain if strict adherence to the marine Class A FC bacteria standard is necessary during the late fall and winter periods.

Table 5. Description of TMDL alternative allocation scenarios.

Alternative 0: Baseline Conditions	
WWTPs and Seafood Processors	At permitted flow and worst case FC concentration (1998-2002 data)
Upper Willapa River	Set at 1998 flow and FC concentrations
Other tributaries	Set at 1998 flow and FC concentrations
Cow pasture	Load determined from estimated 5 to 50 cows in pasture at various times
Municipal stormwater	Based on 1998 estimated rainfall.
Alternative 1	
WWTPs and Seafood Processors	No reduction from base condition
Upper Willapa River	FC set to geometric mean of 58.2 cfu/100mL (per upper Willapa TMDL)
Other tributaries	FC set to geometric mean of 100 cfu/100mL (water quality standard)
Cow pasture	No reduction from base condition
Municipal stormwater	No reduction from base condition.
Alternative 2	
WWTPs and Seafood Processors	Set to permitted flow rates; FC set to 200 cfu/100mL
Upper Willapa River	FC set to geometric mean of 58.2 cfu/100mL (per upper Willapa TMDL)
Other tributaries	FC set to geometric mean of 100 cfu/100mL (water quality standard)
Cow pasture	No reduction from base condition
Municipal stormwater	No reduction from base condition.
Alternative 3	
WWTPs and Seafood Processors	Set to permitted flow rates; FC set to 200 cfu/100mL
Upper Willapa River	FC set to geometric mean of 58.2 cfu/100mL (per upper Willapa TMDL)
Other tributaries	FC set to geometric mean of 100 cfu/100mL (water quality standard)
Cow pasture	Load reduced 90% from base condition.
Municipal stormwater	No reduction from base condition.
Alternative 4	
WWTPs and Seafood Processors	Set to permitted flow rates; FC set to 200 cfu/100mL
Upper Willapa River	FC set to geometric mean of 58.2 cfu/100mL (per upper Willapa TMDL)
Other tributaries	FC set to geometric mean of 100 cfu/100mL (water quality standard)
Cow pasture	Load reduced 90% from base condition.
Municipal stormwater	Load reduced 90% from base condition.
Alternative 5	
WWTPs and Seafood Processors	Set to permitted flow rates; FC set to 200 cfu/100mL
Upper Willapa River	FC set to geometric mean of 58.2 cfu/100mL (per upper Willapa TMDL)
Other tributaries	FC set to geometric mean of 25 cfu/100mL (water quality standard)
Cow pasture	Load reduced 90% from base condition
Municipal stormwater	Load reduced 90% from base condition.
Alternative 6	
WWTPs and Seafood Processors	Set to permitted flow rates; FC set to 200 cfu/100mL
Upper Willapa River	FC set to geometric mean of 25 cfu/100mL (per upper Willapa TMDL)
Other tributaries	FC set to geometric mean of 25 cfu/100mL (water quality standard)
Cow pasture	Load reduced 90% from base condition
Municipal stormwater	Load reduced 90% from base condition.

TMDL Allocation Results

The TMDL fecal coliform targets for this fecal coliform TMDL were calculated based on a concentration and flow rates to give fecal coliform count loads for each source. To meet the TMDL target endpoints, concentration-based load allocations were established for all sources included in the Willapa River WASP model. This allocation of fecal coliform loads attempts to address the criteria compliance requirements under various hydrologic conditions using a dynamic modeling approach. A summary indicating whether or not the freshwater and marine water quality standards were protected for a given allocation scenario is shown in Table 6. The calculated fecal coliforms loads for the baseline conditions and for allocation alternatives 3 and 6 are provided in Table 7. The TMDL allocations are shown for two seasonal time periods: Spring-Summer period (April-October) and a late Fall period (November-December).

Table 6. TMDL alternatives and protection of FC bacteria water quality standards.

TMDL Alternative	Is Geometric Mean WQS protected?				Is 90th Percentile WQS protected?			
	Apr-Oct		Nov-Dec		Apr-Oct		Nov-Dec	
	Freshwater	Marine	Freshwater	Marine	Freshwater	Marine	Freshwater	Marine
0	No	No	No	No	No	No	No	No
1	Yes	No	Yes	No	Yes	Yes	Yes	No
2	Yes	No	Yes	No	Yes	Yes	Yes	No
3	Yes	Yes	Yes	No	Yes	Yes	Yes	No
4	Yes	Yes	Yes	No	Yes	Yes	Yes	No
5	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
6	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 7. Seasonal allocation results for Lower Willapa River FC bacteria TMDL.

	Spring-Summer (April-October)			Late Fall (November-December)		
Source	**Baseline cfu**	**TMDL Alt. 3 cfu**	**Reduction**	**Baseline cfu**	**TMDL Alt. 6 cfu**	**Reduction**
Raymond WWTP	1.996E+11	7.950E+10	60.2%	8.552E+10	3.407E+10	60.2%
South Bend WWTP	5.287E+10	1.988E+10	62.4%	2.266E+10	8.518E+09	62.4%
Coast Seafoods	1.154E+12	5.247E+09	99.5%	4.947E+11	2.249E+09	99.5%
South Bend Packers	4.240E+09	5.299E+08	87.5%	1.817E+09	2.271E+08	87.5%
East Point Seafoods	1.895E+11	1.723E+10	90.9%	8.121E+10	7.382E+09	90.9%
Stormwater (South Bend)	3.405E+13	3.405E+13	0.0%	8.157E+13	8.157E+12	90.0%
Stormwater (Raymond)	1.037E+14	1.037E+14	0.0%	2.483E+14	2.483E+13	90.0%
Total WLA	**1.393E+14**	**1.378E+14**	**1.1%**	**3.306E+14**	**3.304E+13**	**90.0%**
Waterfowl and wildlife	6.010E+14	6.010E+14	0.0%	2.350E+14	2.350E+14	0.0%
Upper Willapa River	4.689E+13	3.832E+13	18.3%	4.469E+14	9.059E+13	79.7%
Other tributaries and pasture	3.489E+15	4.071E+14	88.3%	1.728E+15	1.900E+14	89.0%
Total LA	**4.137E+15**	**1.046E+15**	**74.7%**	**2.410E+15**	**5.156E+14**	**78.6%**
Total WLA + LA	**4.276E+15**	**1.184E+15**	**72.3%**	**2.740E+15**	**5.486E+14**	**80.0%**

Seasonal Variation

Seasonal variations were included in the study design. The TMDL was developed for two seasons: spring-summer (April-October) and late fall (October-December). The spring-summer period is characterized by low stream flow in which the river is more susceptible to impacts from point sources of FC bacteria. The late fall period has relatively higher stream flows and bacteria loads, both of which impact bacteria levels in the lower Willapa River. The TMDL allocations were developed using these seasonal divisions.

Margin of Safety

A margin of safety (MOS) is required in all TMDLs to ensure that the TMDL is sufficiently protective of water quality when the uncertainty of the analysis is considered. The MOS for the freshwater reaches of lower Willapa River upstream of river mile 1.8 are evident in the transect results presented in Appendix B (Figures B-01 to B-04). For allocation alternative 6, the FC concentrations range from 1% to about 90% below the geometric mean and 90^{th} percentile water quality standards depending on location along the river.

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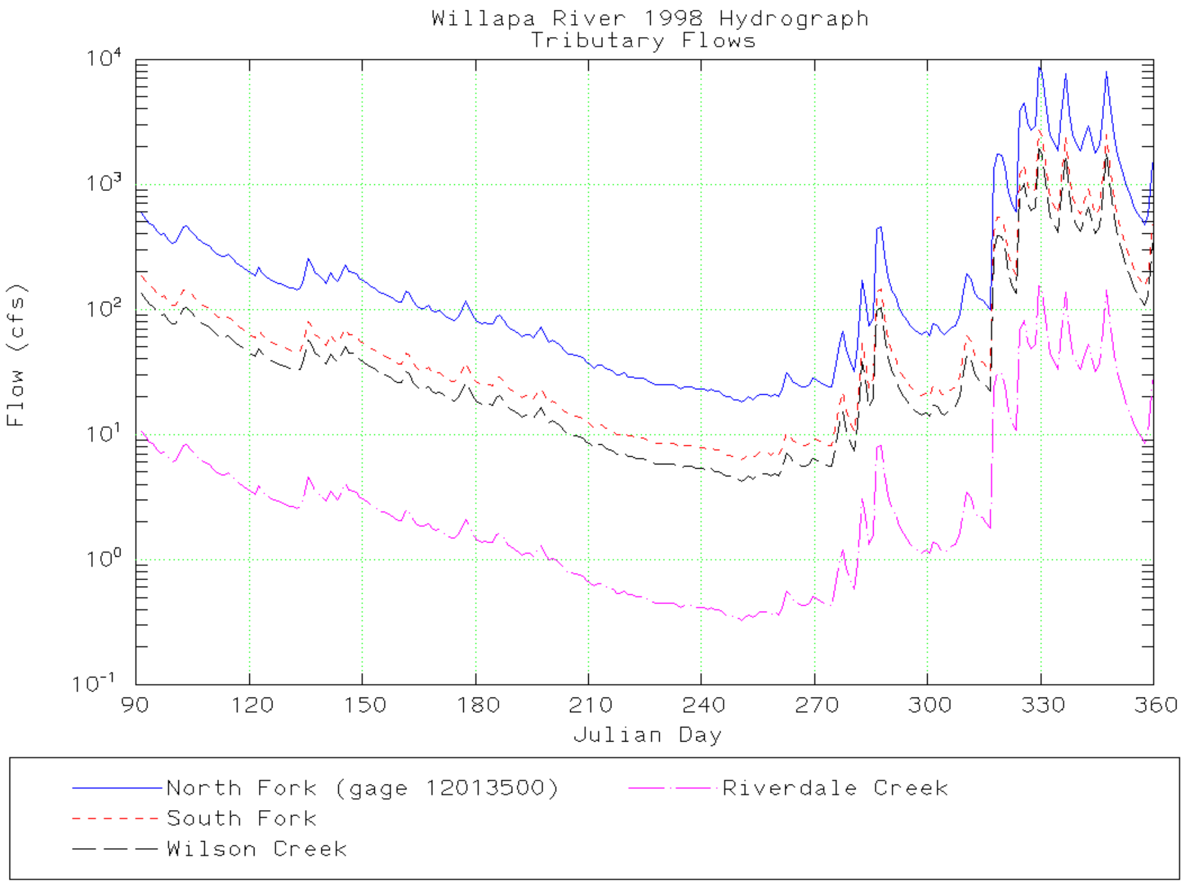
Appendix A

Lower Willapa River
Fecal Coliform Bacteria TMDL

WASP Model Calibration Results

Stream flows for the 1998 calibration period for selected tributaries are shown below.



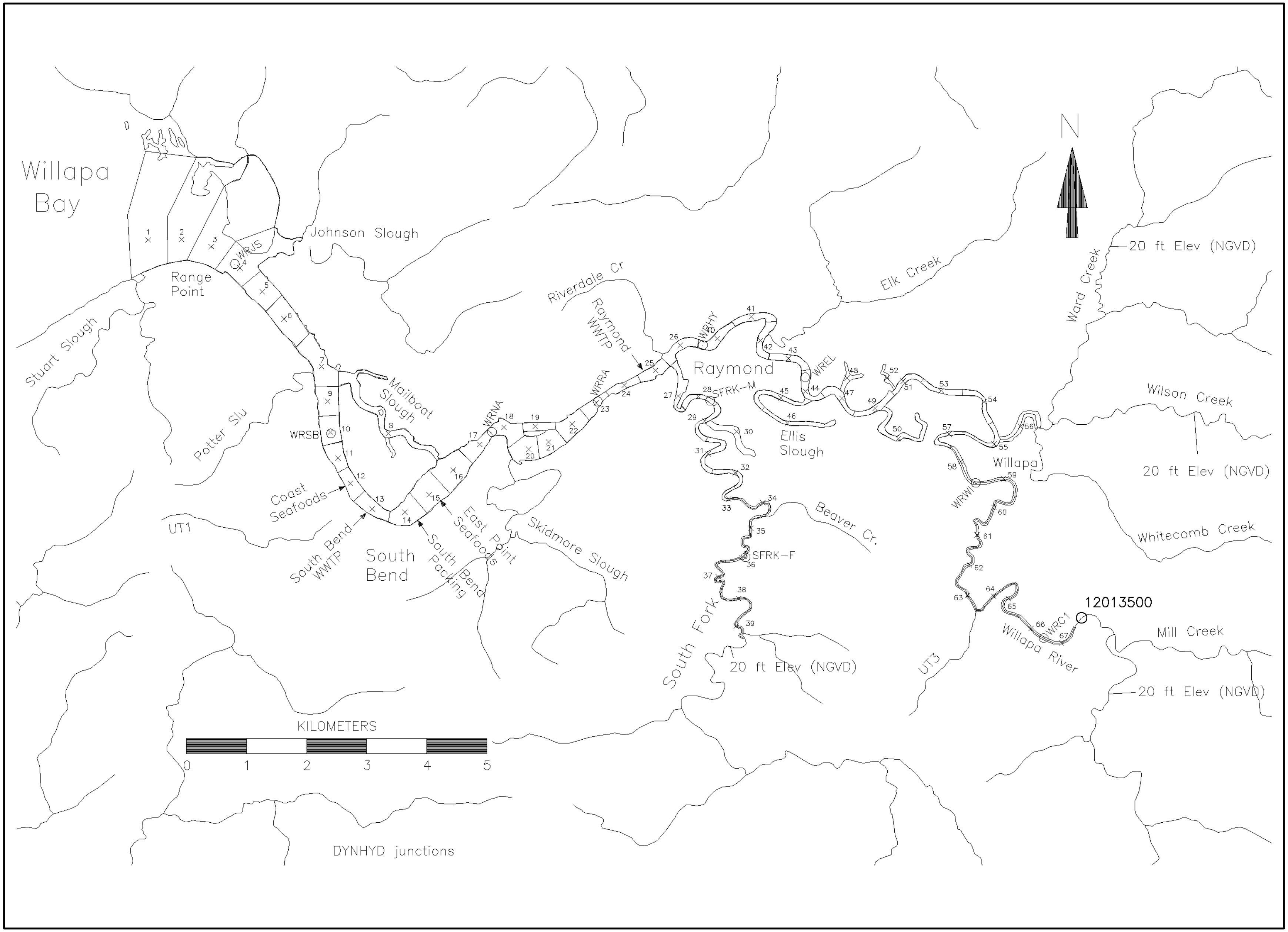


Figure A-01. DYNHYD model segmentation for Lower Willapa River FC bacteria TMDL.

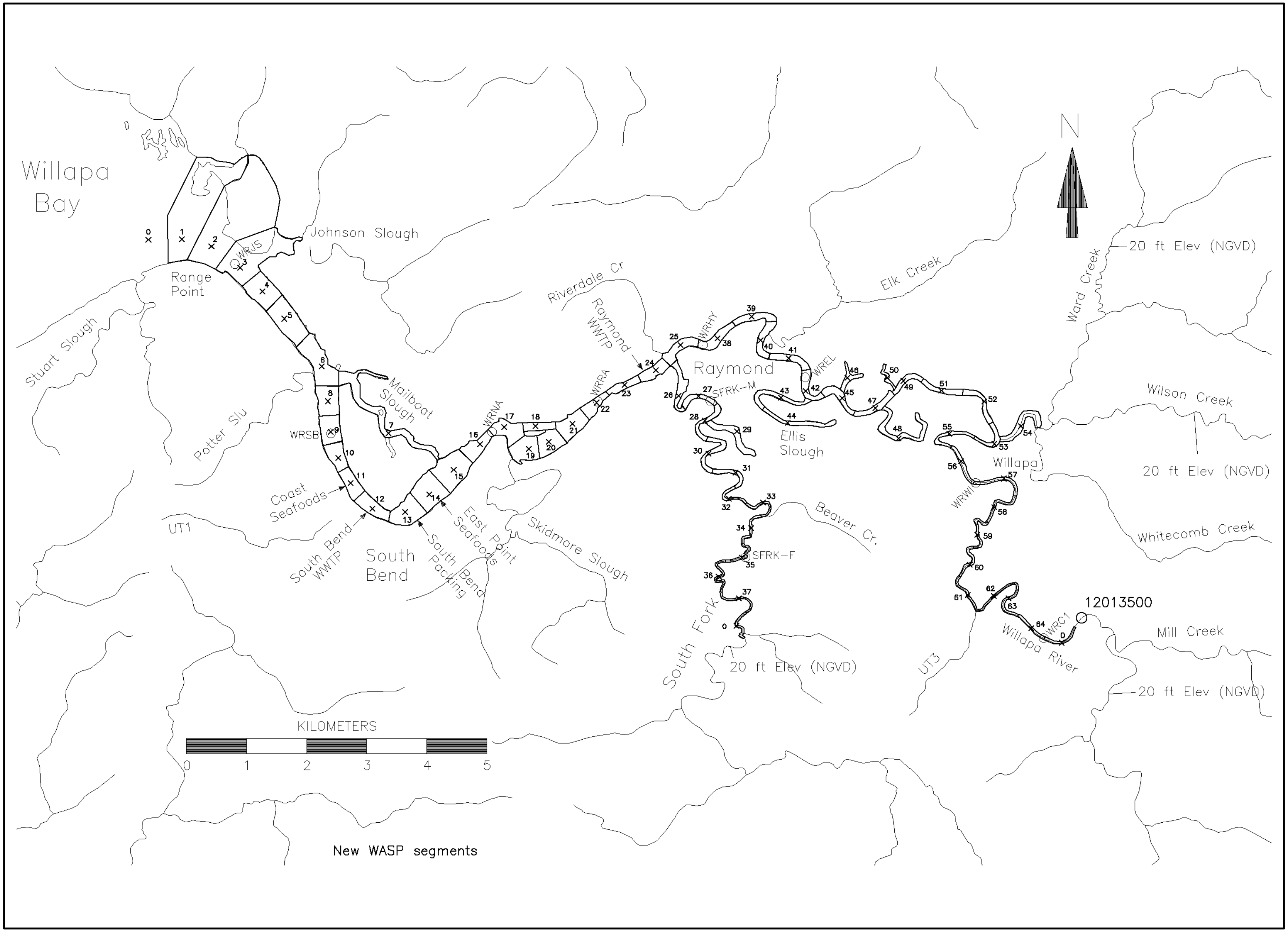


Figure A-02. WASP model segmentation for Lower Willapa River FC bacteria TMDL.

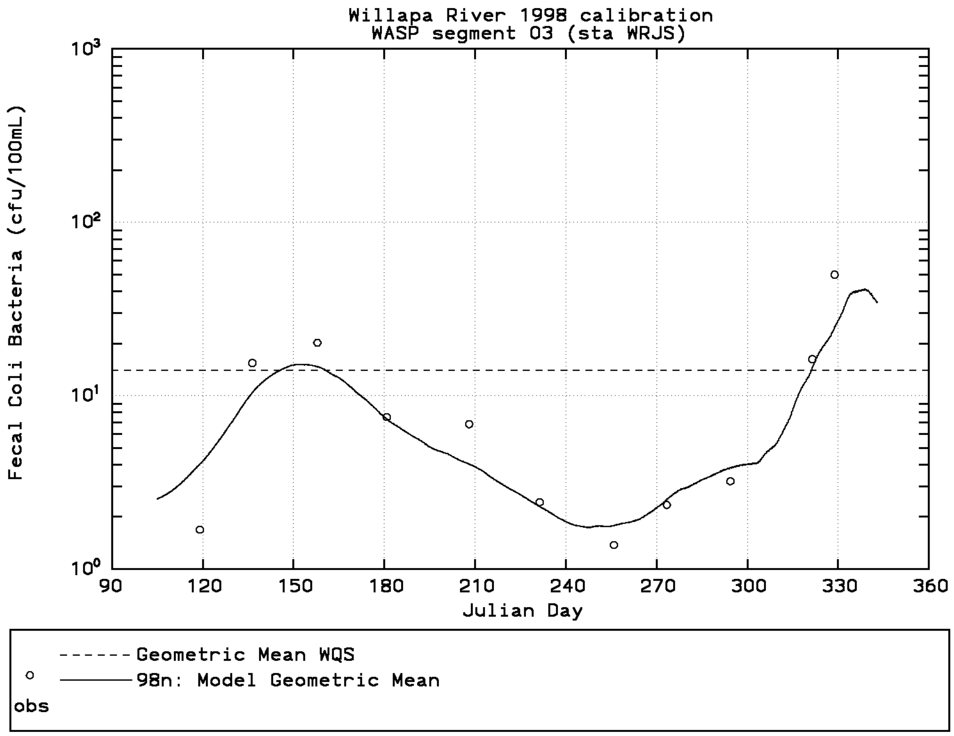


Figure A-03a. Willapa River FC bacteria calibration, station WRJS (geometric mean).

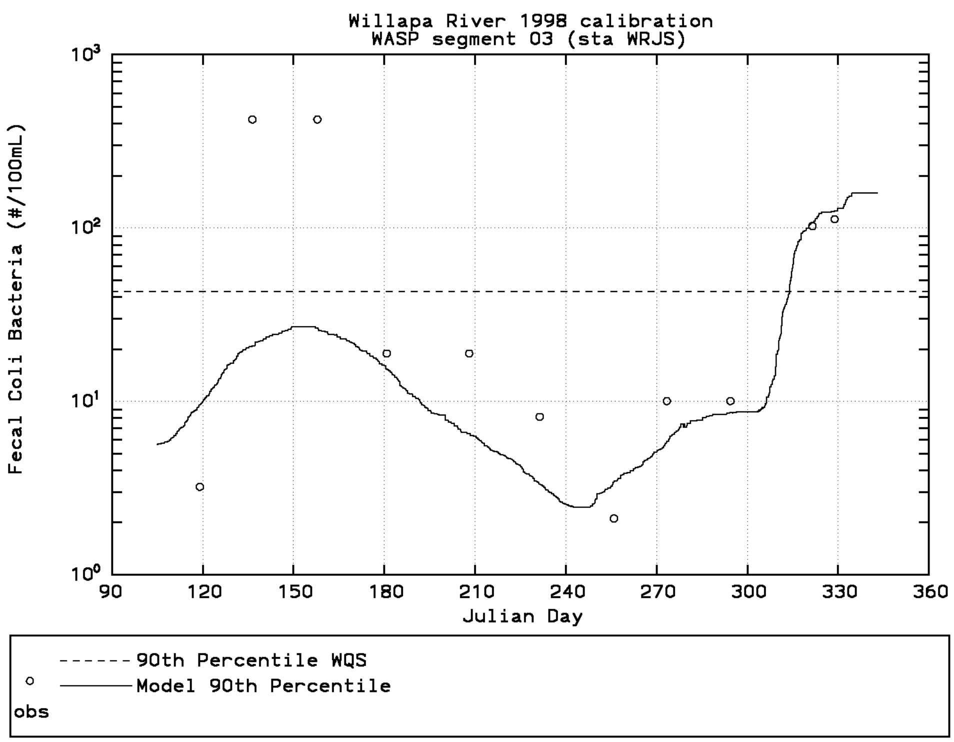


Figure A-03b. Willapa River FC bacteria calibration, station WRJS (90th percentile).

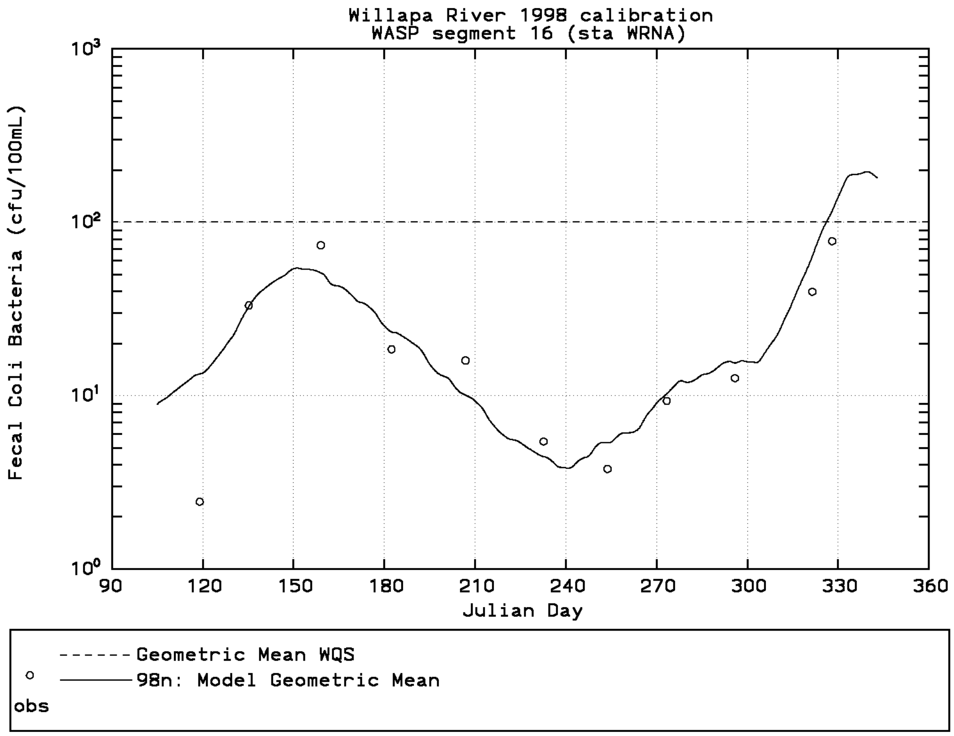


Figure A-04a. Willapa River FC bacteria calibration, station WRNA (geometric mean).

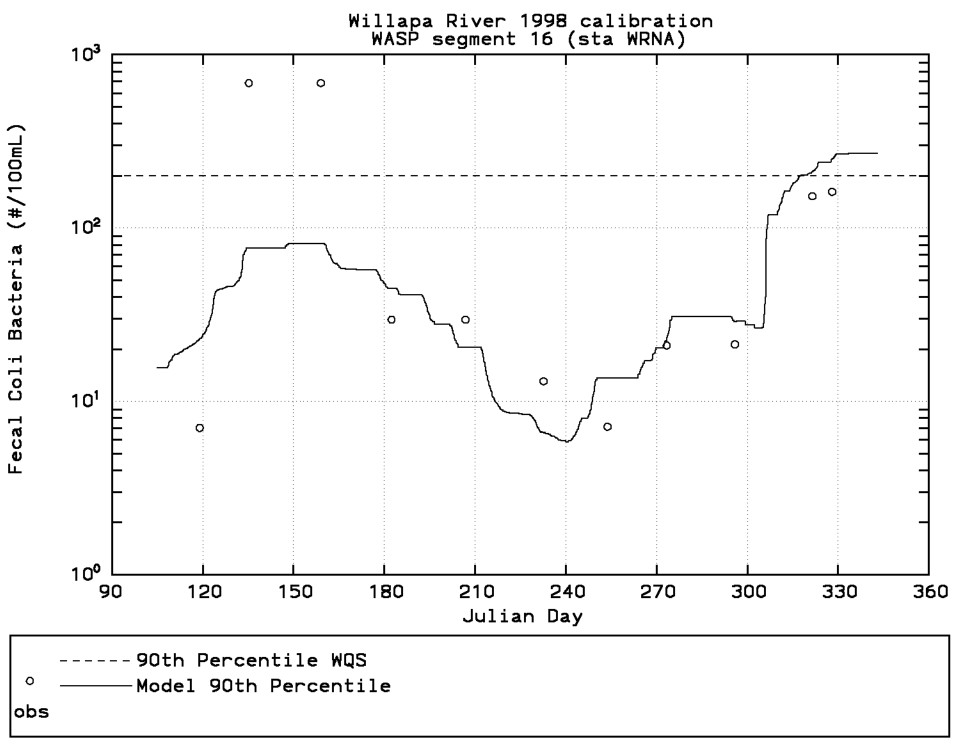


Figure A-04b. Willapa River FC bacteria calibration, station WRNA (90th percentile).

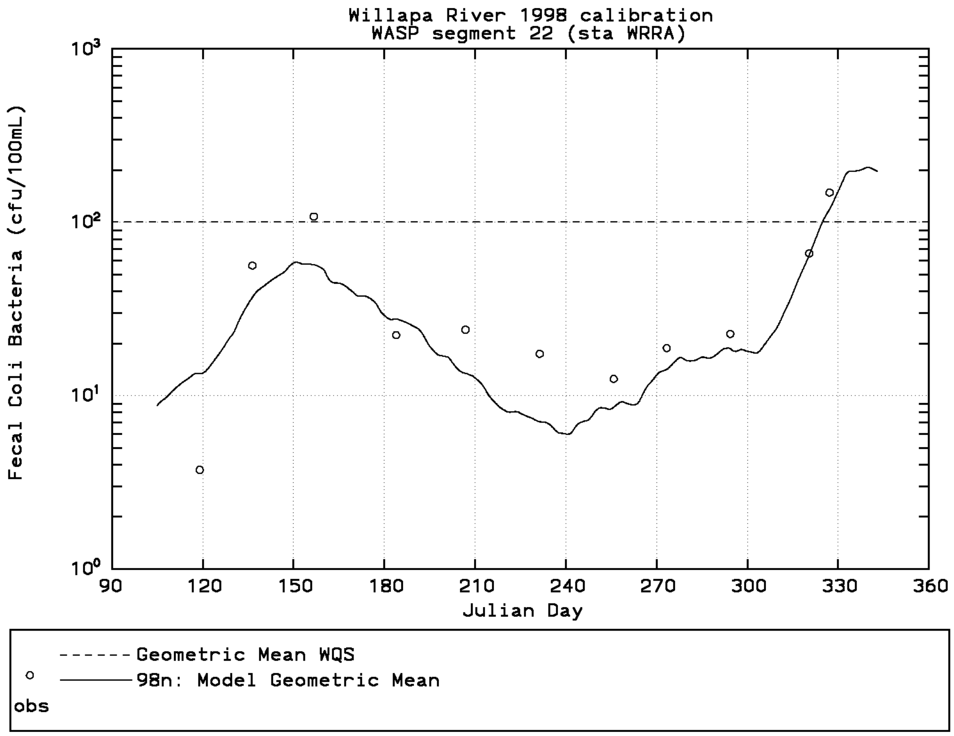


Figure A-05a. Willapa River FC bacteria calibration, station WRRA (geometric mean).

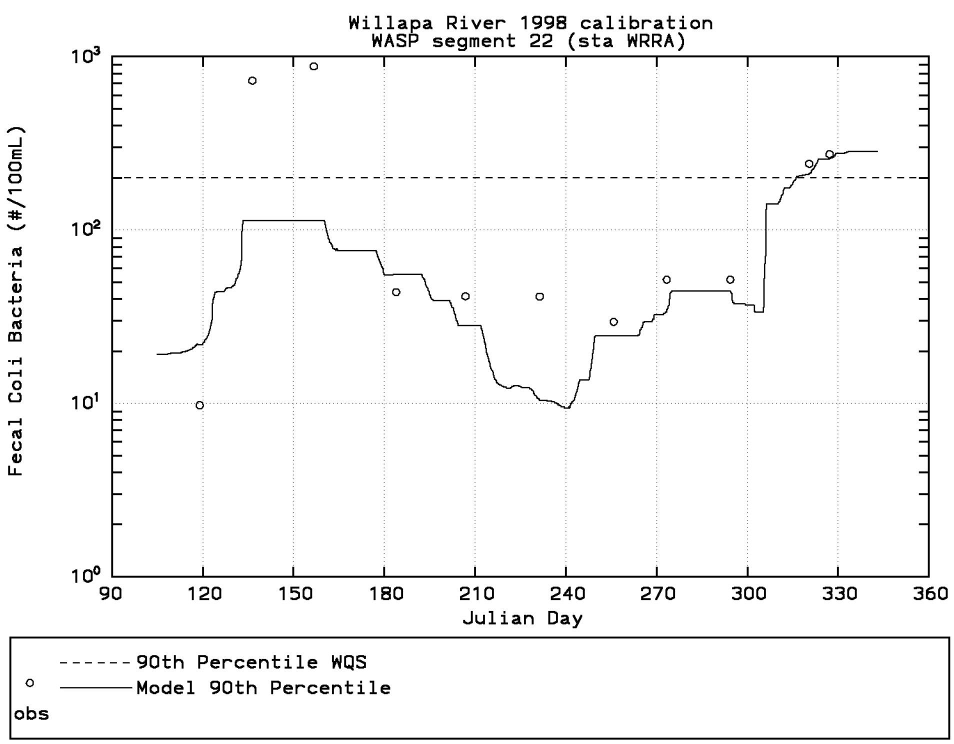


Figure A-05b. Willapa River FC bacteria calibration, station WRRA (90th percentile).

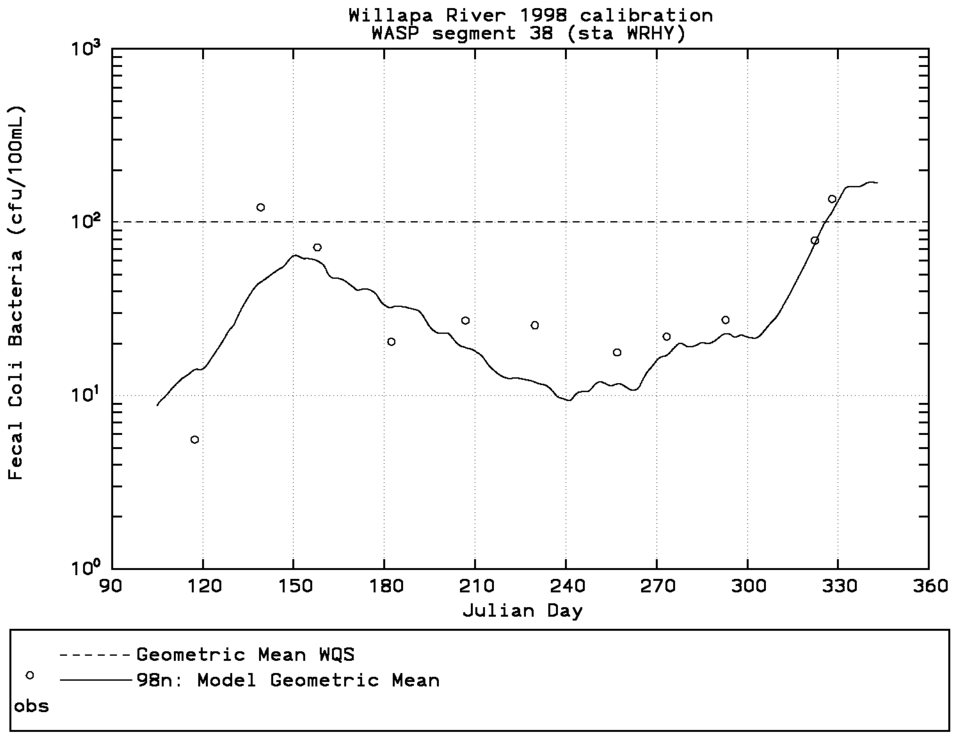


Figure A-06a. Willapa River FC bacteria calibration, station WRHY (geometric mean).

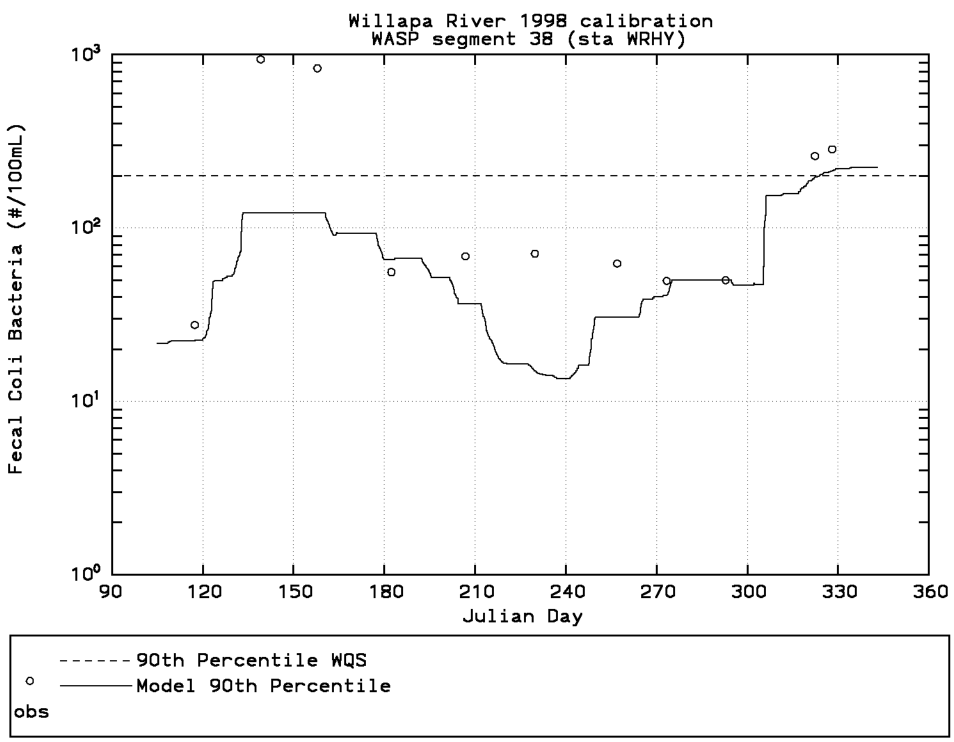


Figure A-06b. Willapa River FC bacteria calibration, station WRHY (90th percentile).

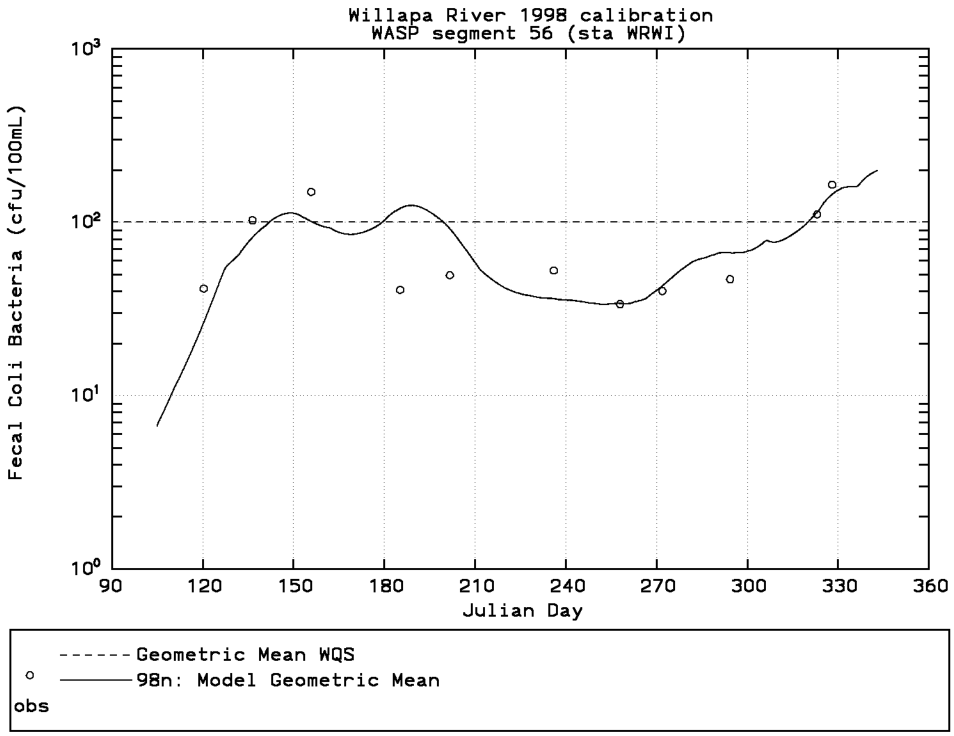


Figure A-07a. Willapa River FC bacteria calibration, station WRWI (geometric mean).

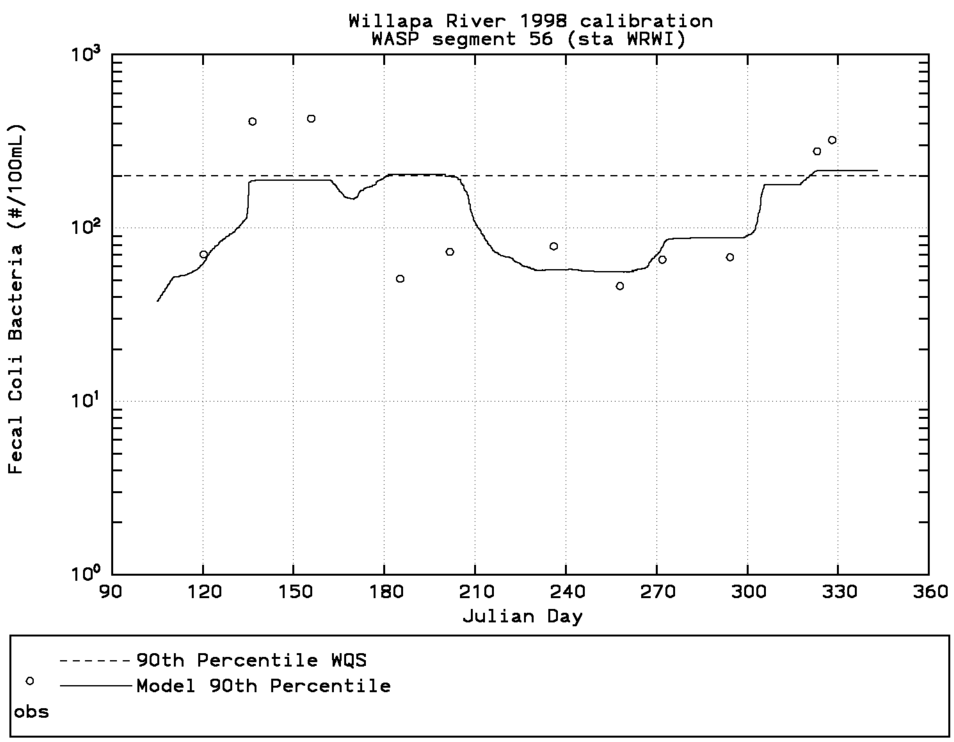


Figure A-07b. Willapa River FC bacteria calibration, station WRWI (90th percentile).

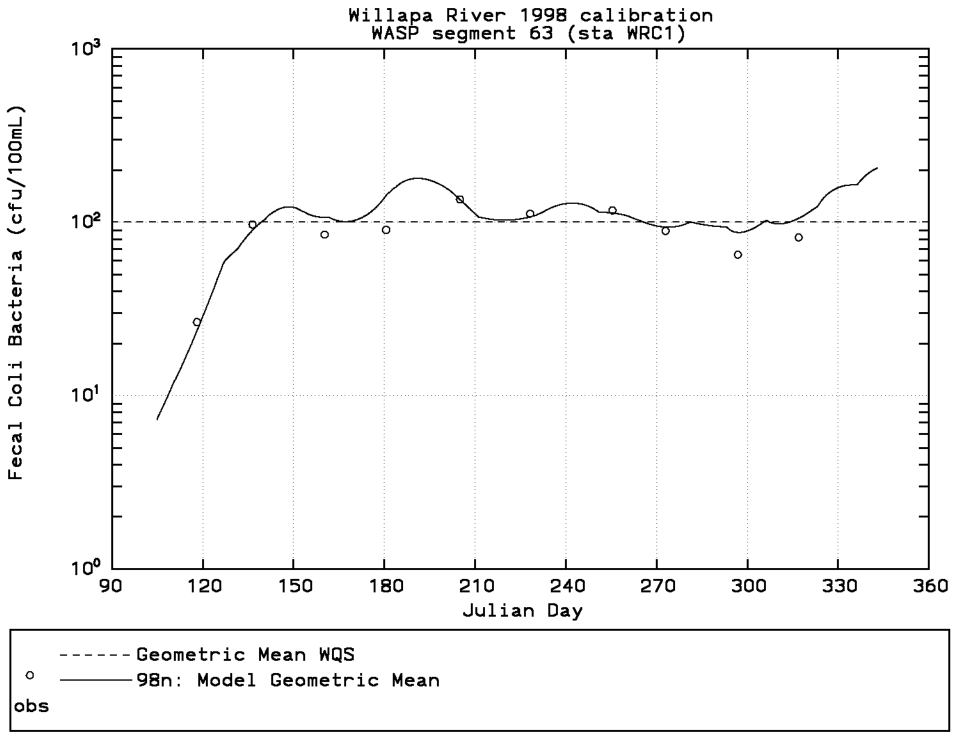


Figure A-08a. Willapa River FC bacteria calibration, station WRC1 (geometric mean).

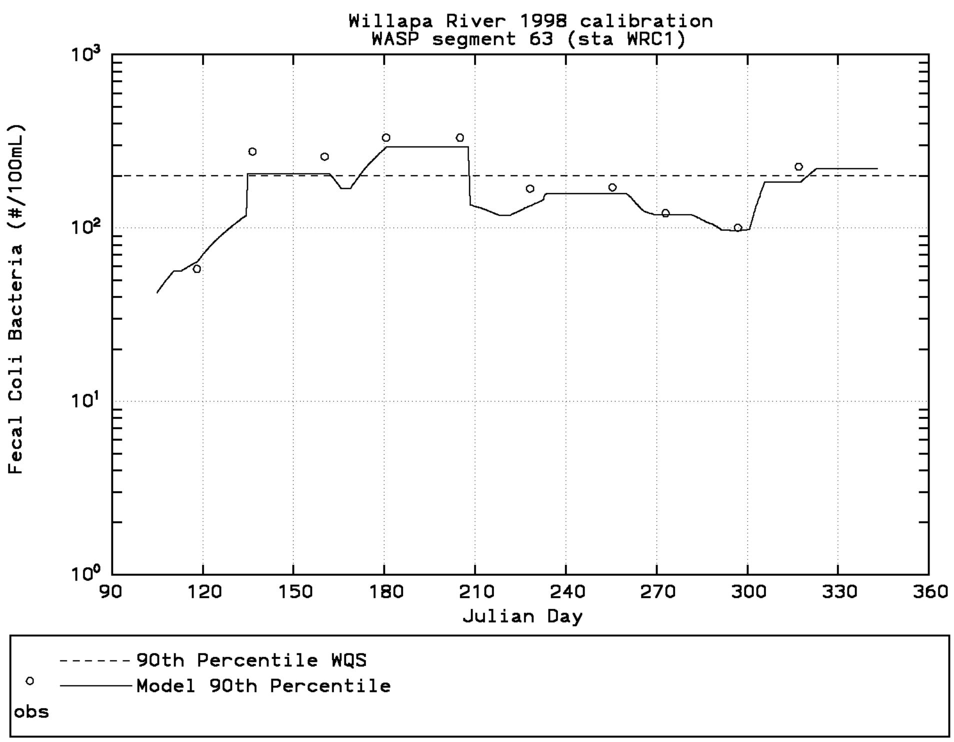


Figure A-08b. Willapa River FC bacteria calibration, station WRC1 (90th percentile).

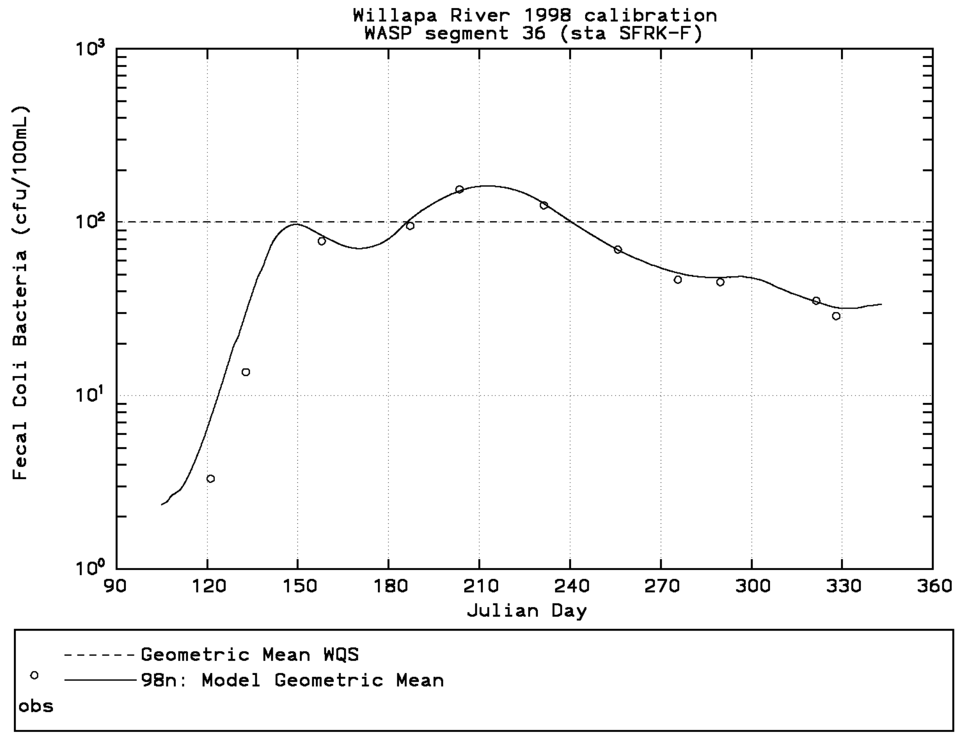


Figure A-09a. South Fork FC bacteria calibration, station SFRK-F (geometric mean).

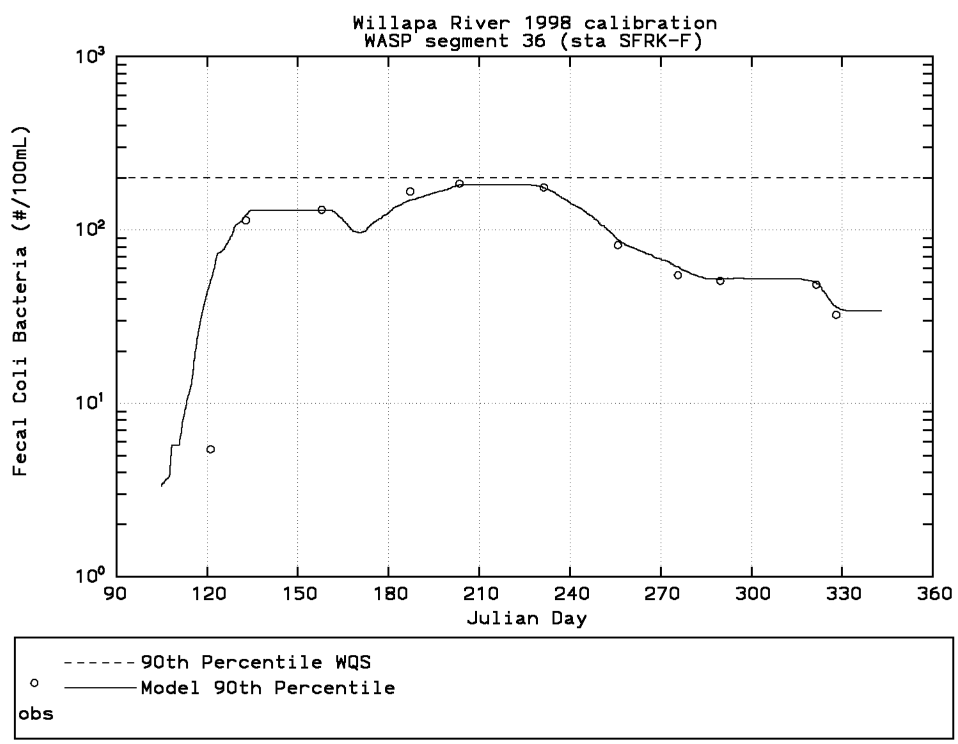


Figure A-09b. South Fork FC bacteria calibration, station SFRK-F (90th percentile).

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Appendix B

Lower Willapa River
Fecal Coliform Bacteria TMDL

TMDL Allocation Scenario Results

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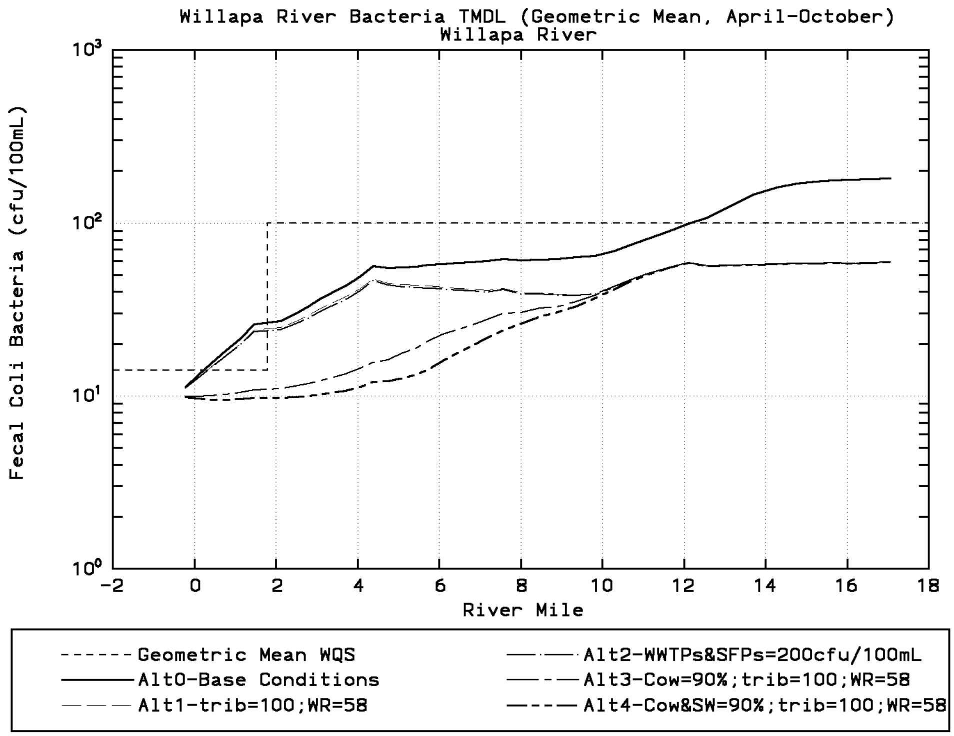

Figure B-01a. Willapa River TMDL allocations, geometric mean (Apr-Oct).

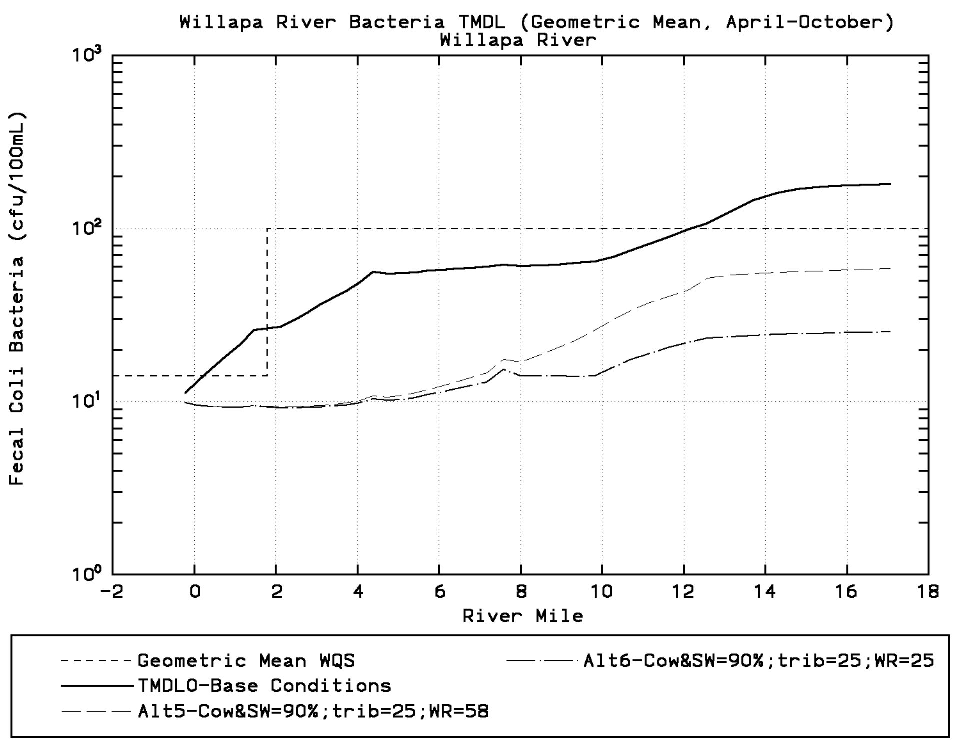

Figure B-01b. Willapa River TMDL allocations, geometric mean (Apr-Oct).

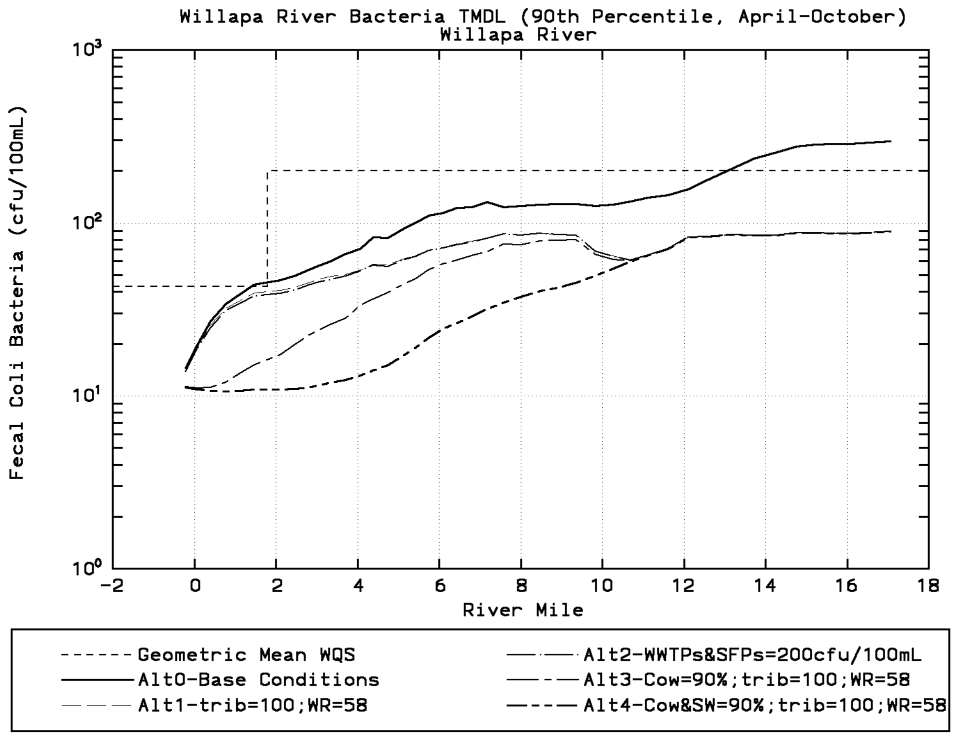

Figure B-02a. Willapa River TMDL allocations, 90th percentile (Apr-Oct).

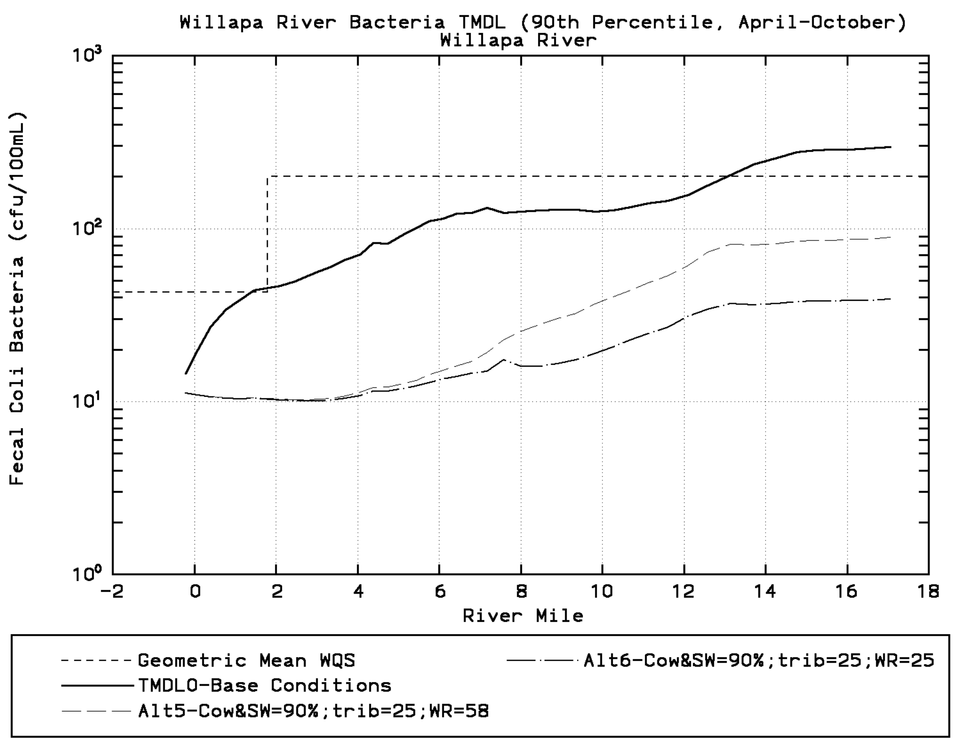

Figure B-02b. Willapa River TMDL allocations, 90th percentile (Apr-Oct).

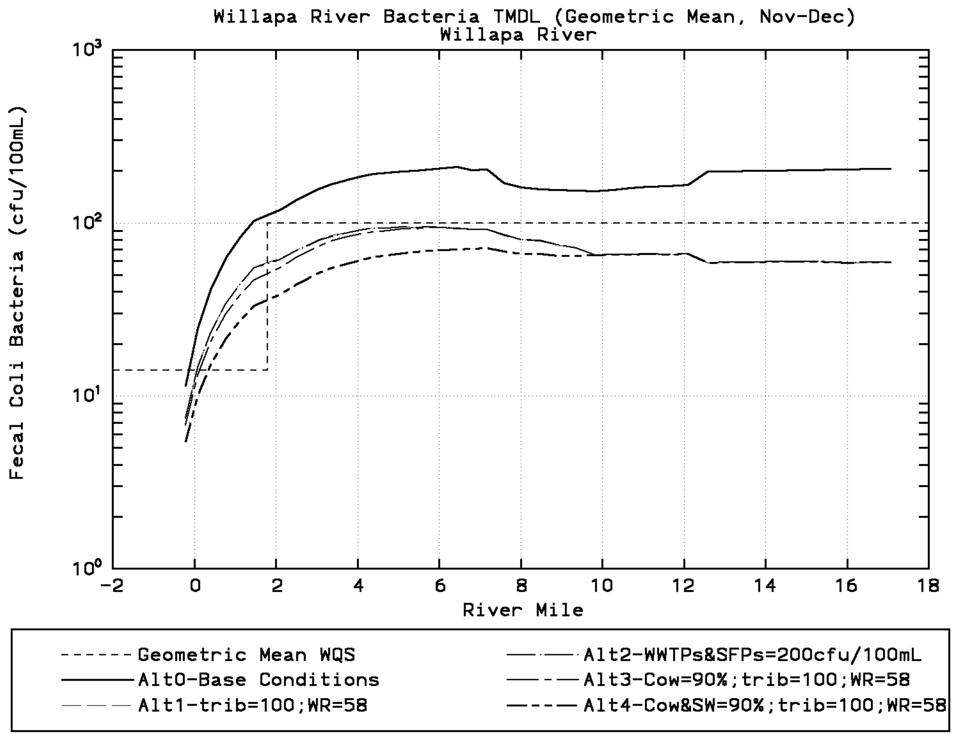

Figure B-03a. Willapa River TMDL allocations, geometric mean (Nov-Dec).

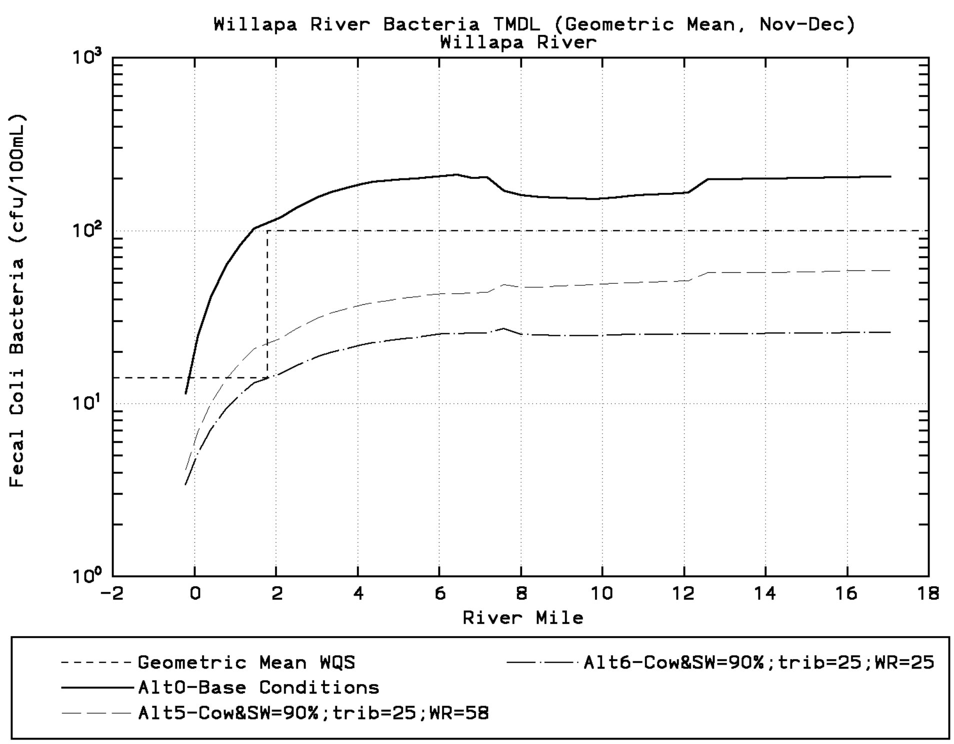

Figure B-03b. Willapa River TMDL allocations, geometric mean (Nov-Dec).

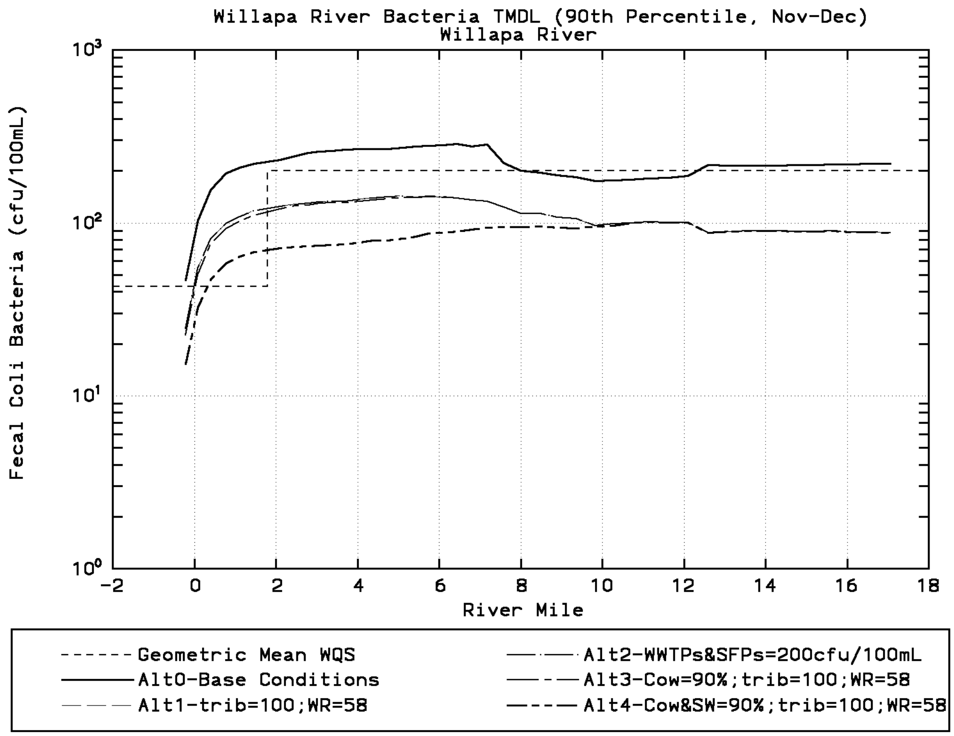

Figure B-04a. Willapa River TMDL allocations, 90th percentile (Nov-Dec).

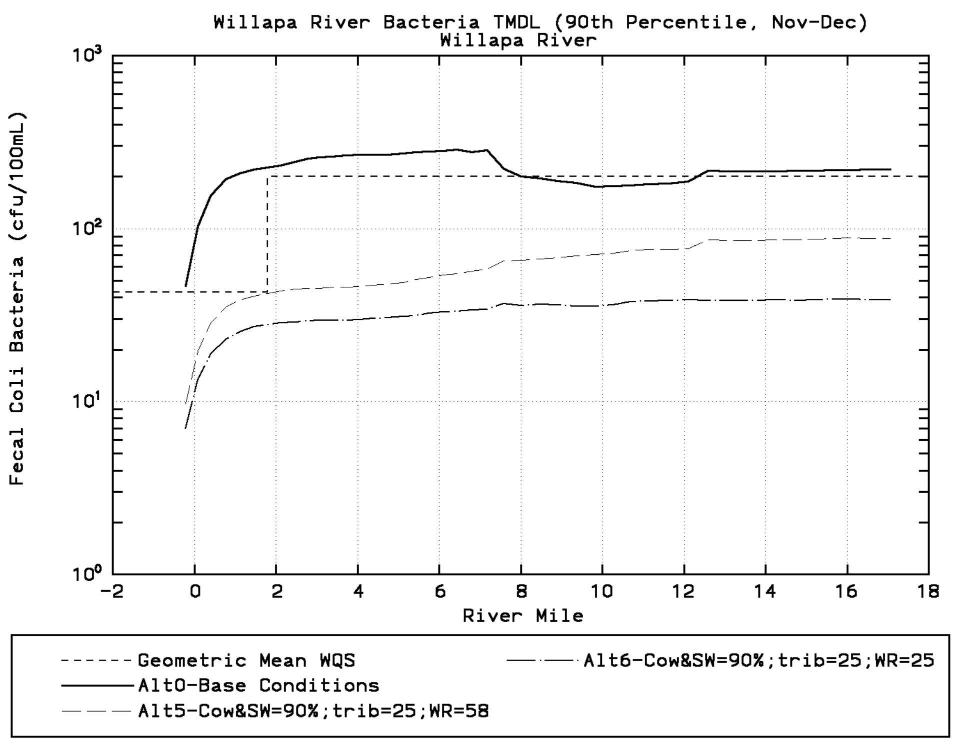

Figure B-04b. Willapa River TMDL allocations, 90th percentile (Nov-Dec).

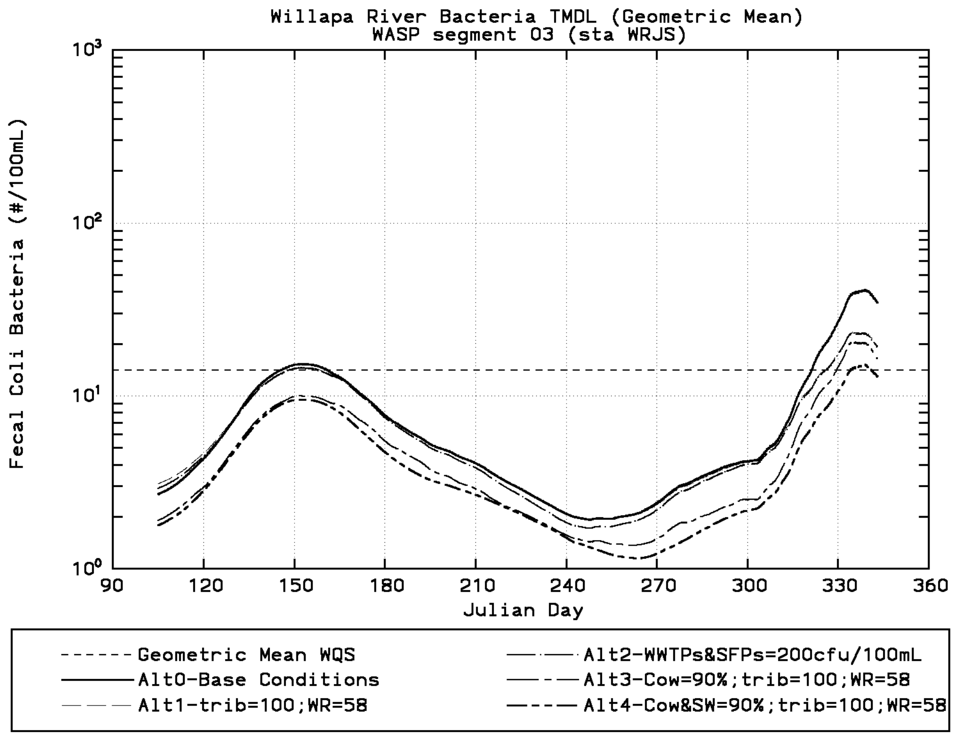

Figure B-05a. Willapa River TMDL allocations, geometric mean at station WRJS.

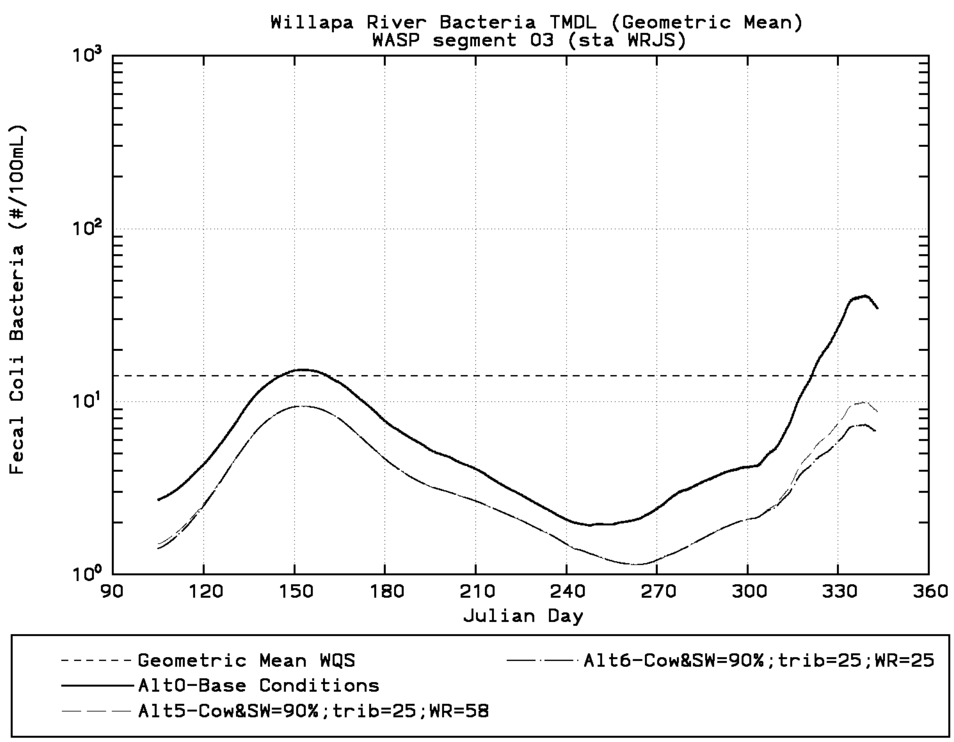

Figure B-05b. Willapa River TMDL allocations, geometric mean at station WRJS.

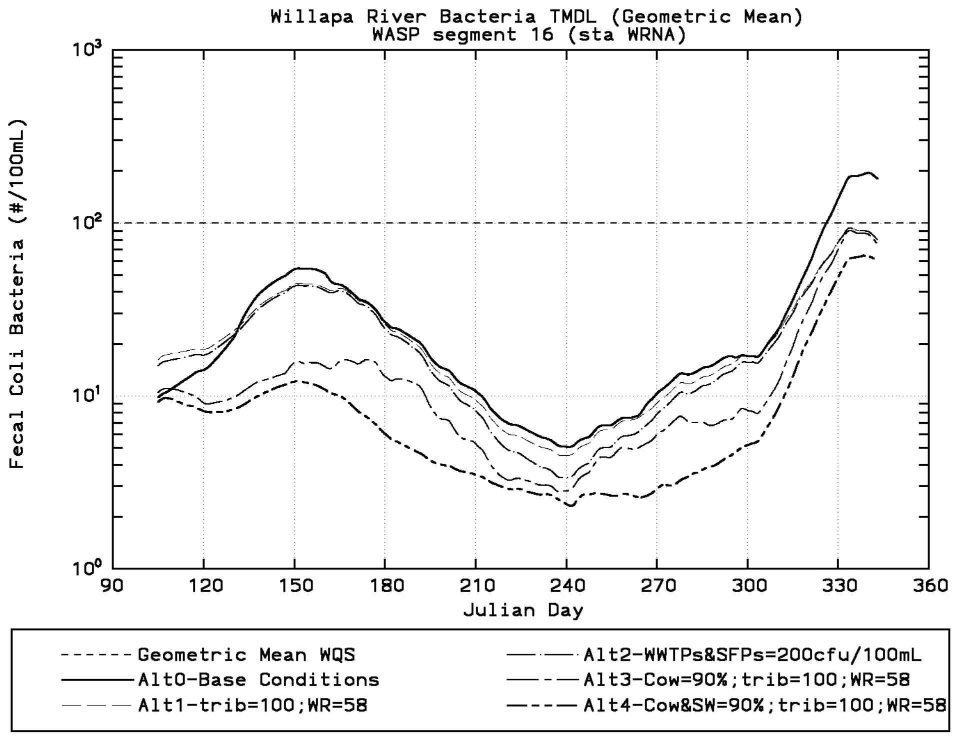

Figure B-06a. Willapa River TMDL allocations, geometric mean at station WRNA.

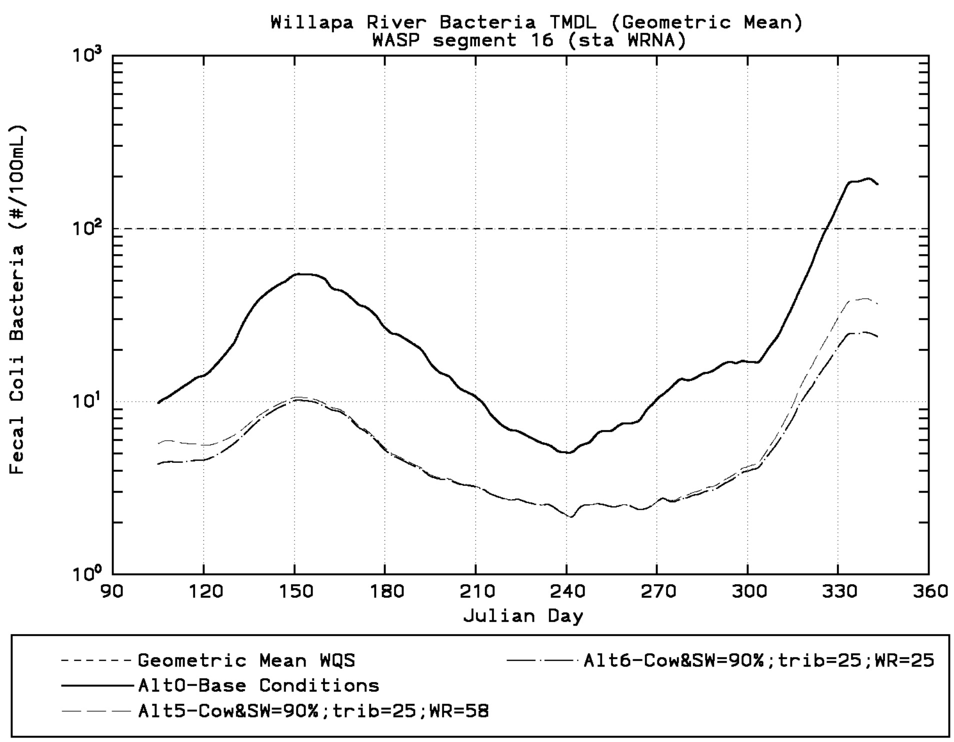

Figure B-06b. Willapa River TMDL allocations, geometric mean at station WRNA.

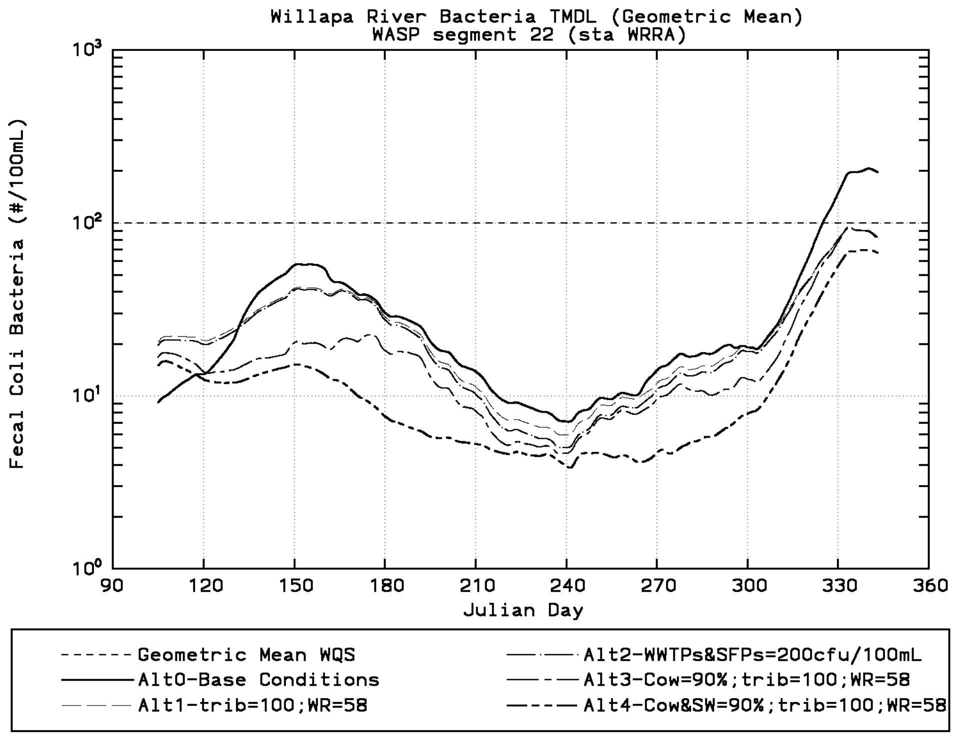

Figure B-07a. Willapa River TMDL allocations, geometric mean at station WRRA.

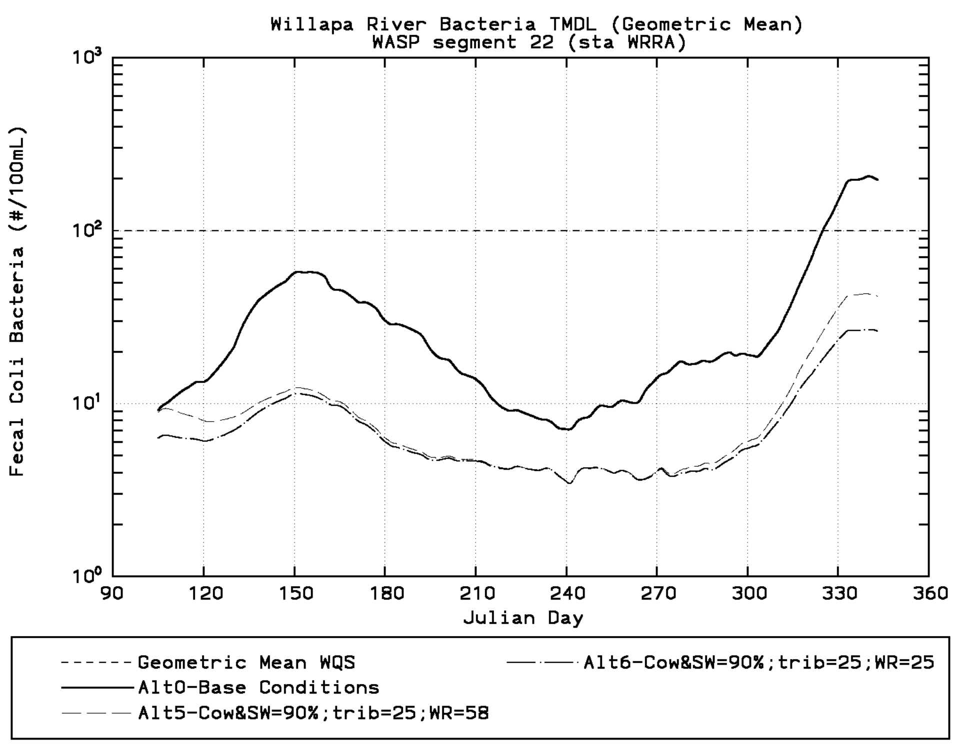

Figure B-07b. Willapa River TMDL allocations, geometric mean at station WRRA.

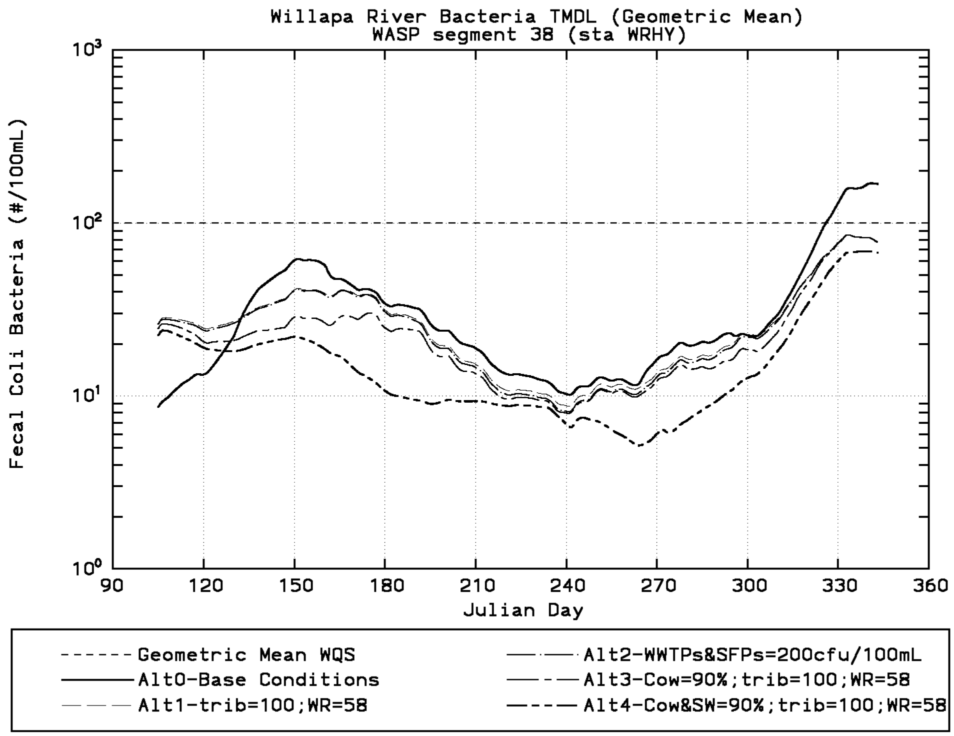

Figure B-08a. Willapa River TMDL allocations, geometric mean at station WRHY.

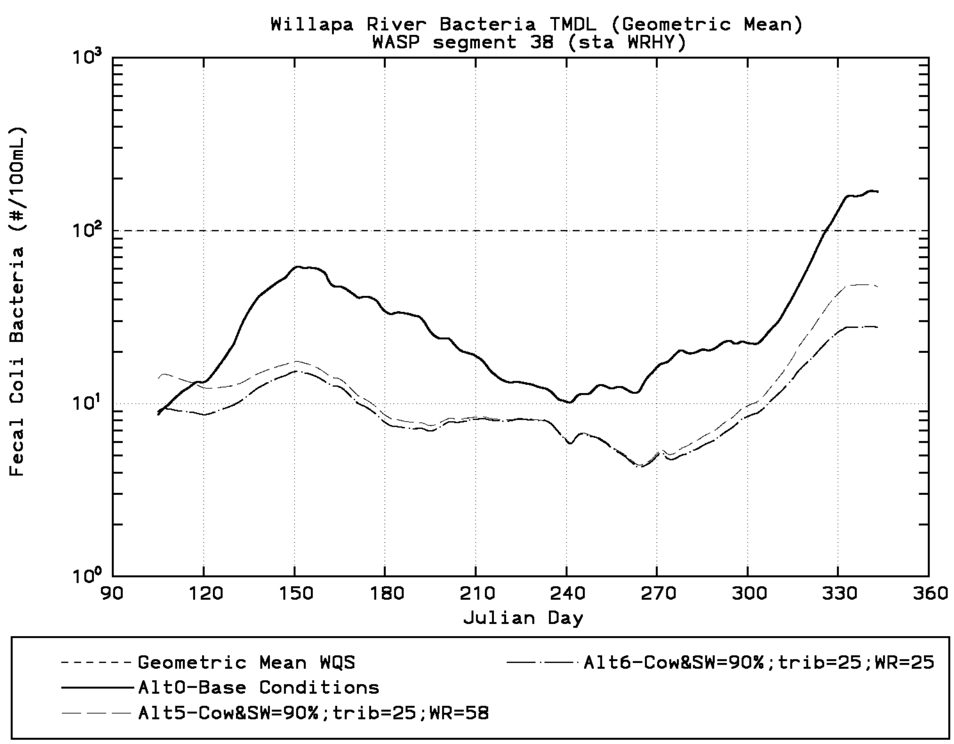

Figure B-08b. Willapa River TMDL allocations, geometric mean at station WRHY.

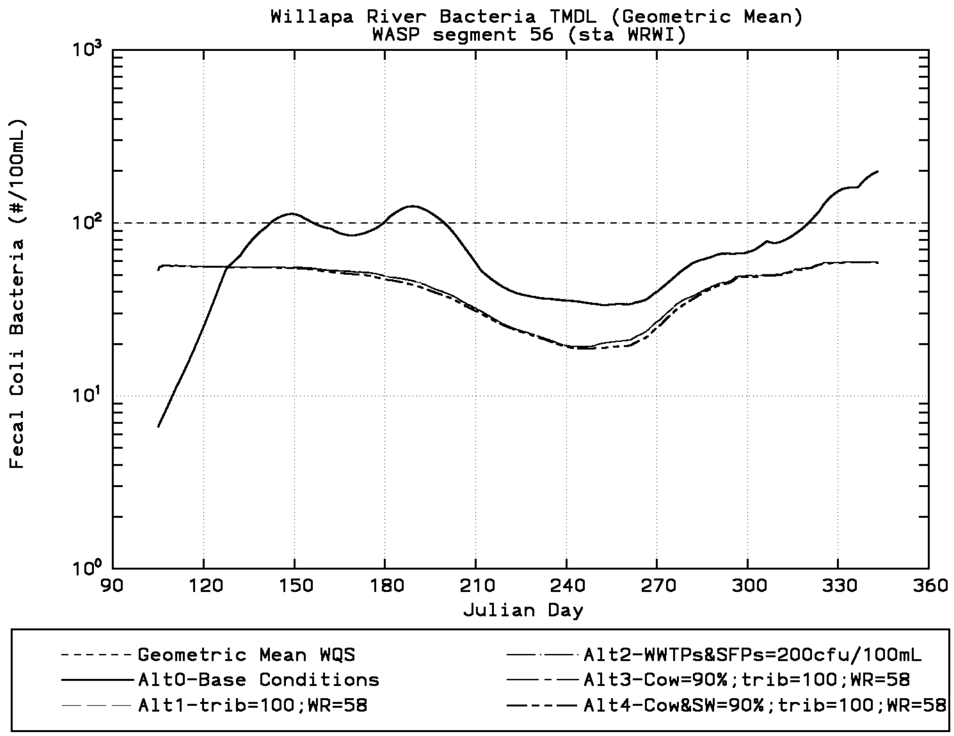

Figure B-09a. Willapa River TMDL allocations, geometric mean at station WRWI.

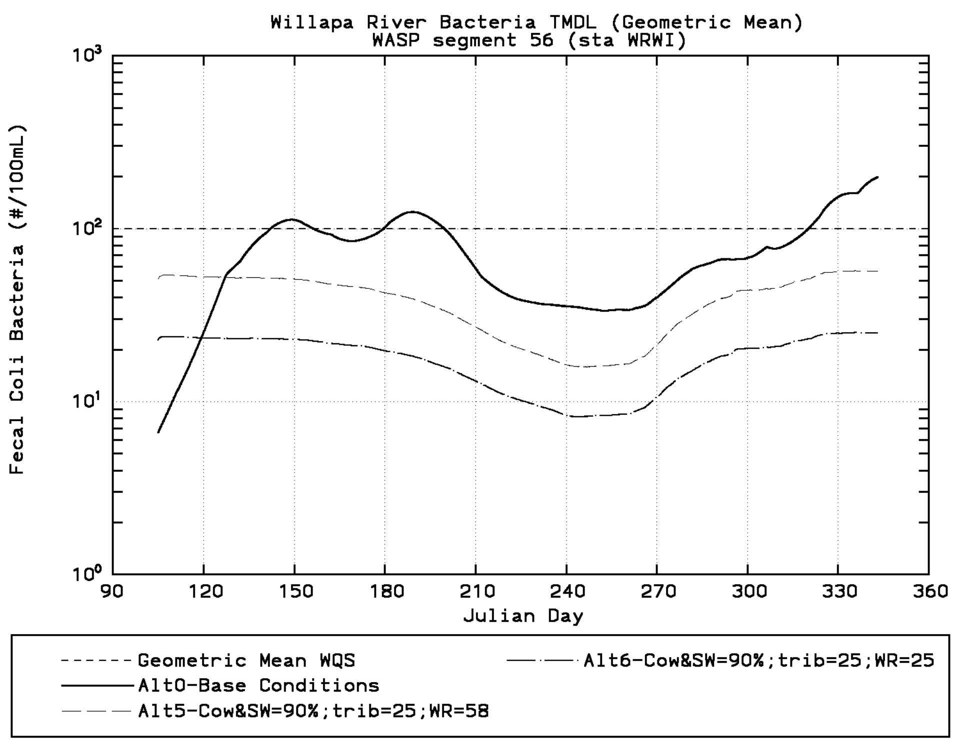

Figure B-09b. Willapa River TMDL allocations, geometric mean at station WRWI.

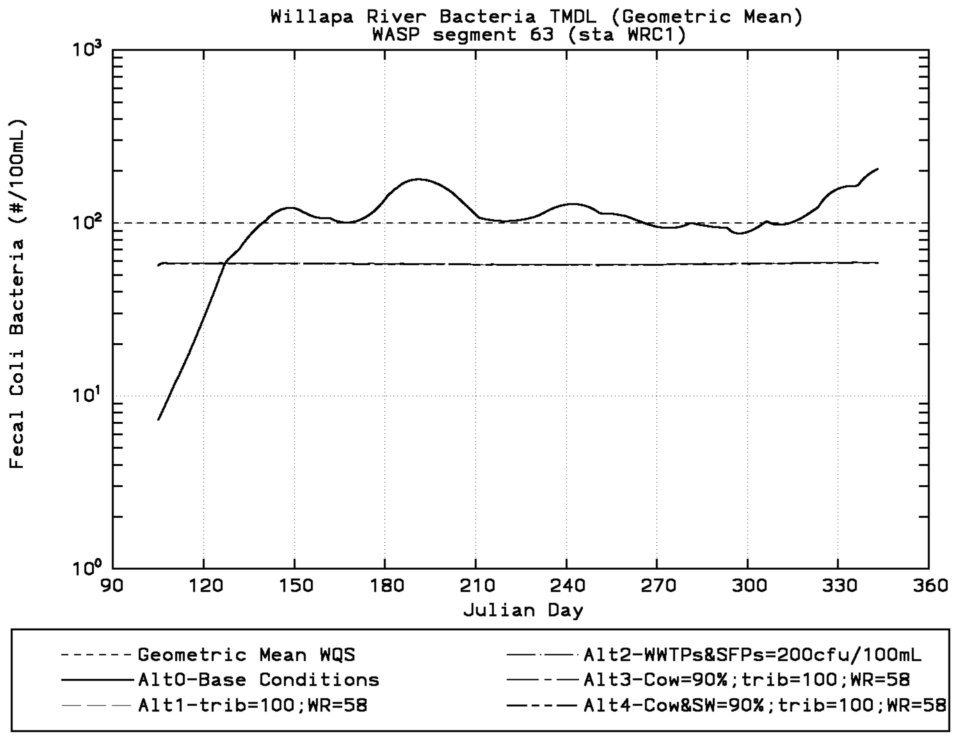

Figure B-10a. Willapa River TMDL allocations, geometric mean at station WRC1.

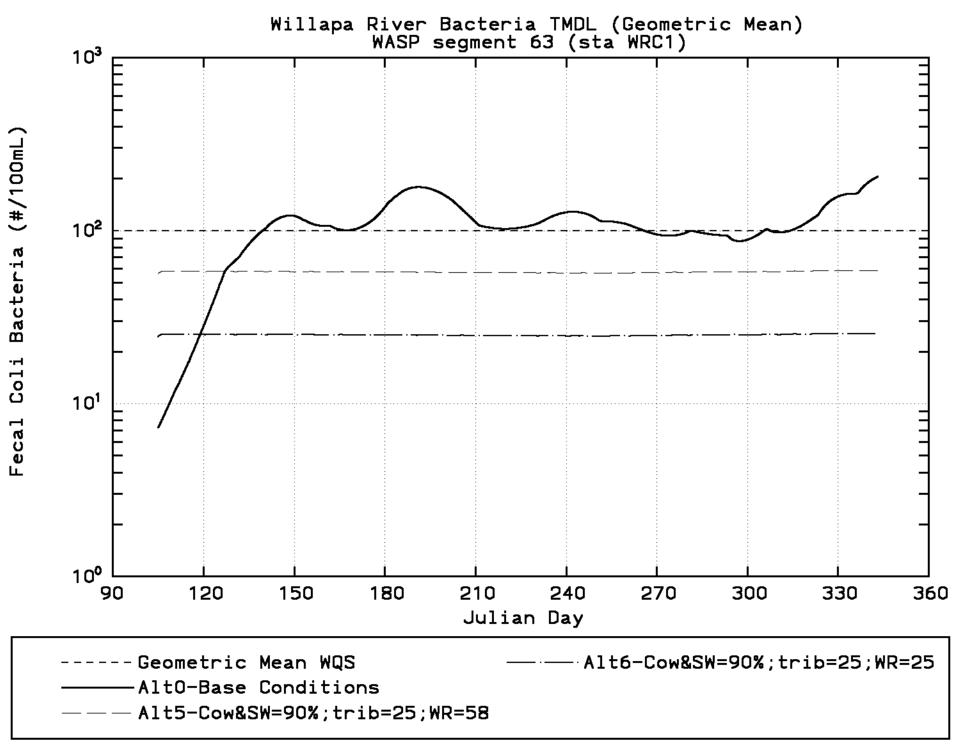

Figure B-10b. Willapa River TMDL allocations, geometric mean at station WRC1.

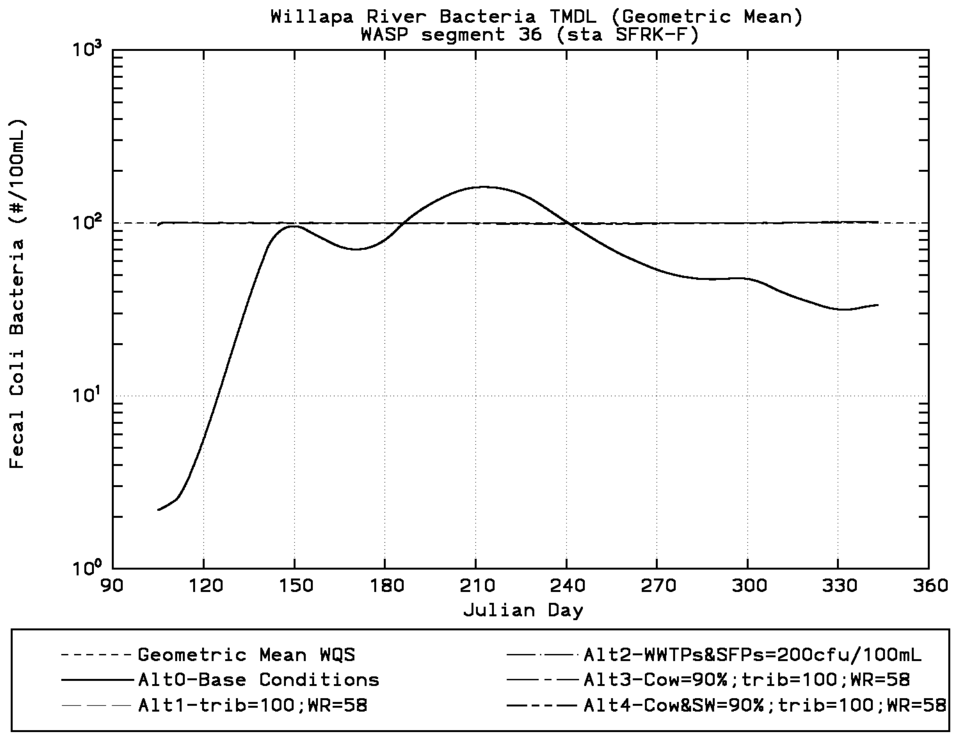

Figure B-11a. Willapa River TMDL allocations, geometric mean at station SFRK-F.

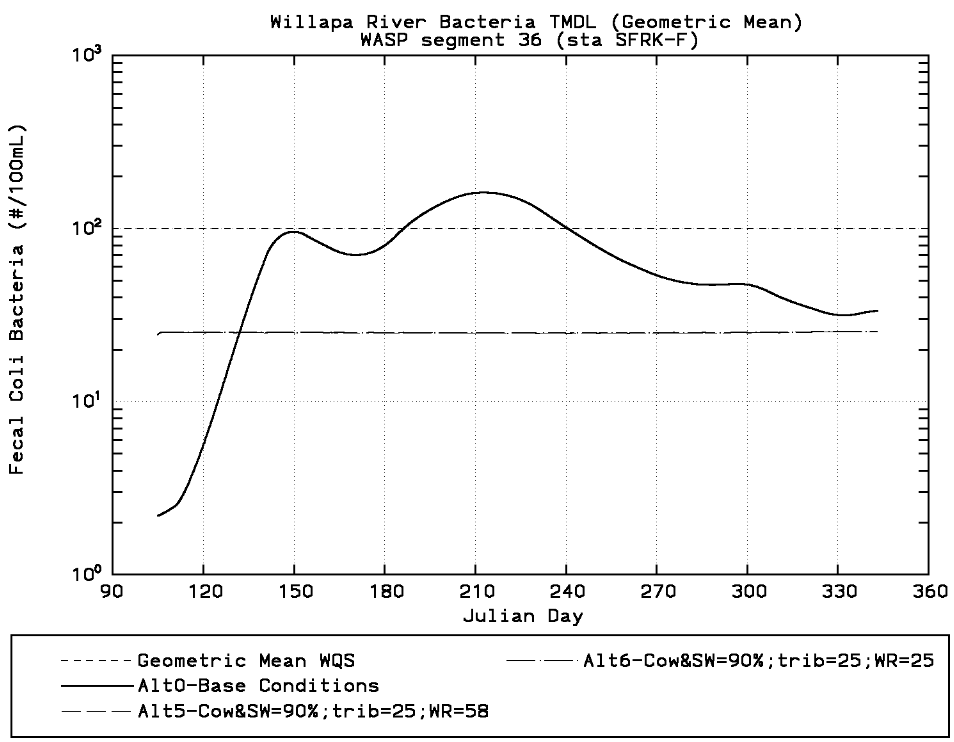

Figure B-11b. Willapa River TMDL allocations, geometric mean at station SFRK-F.

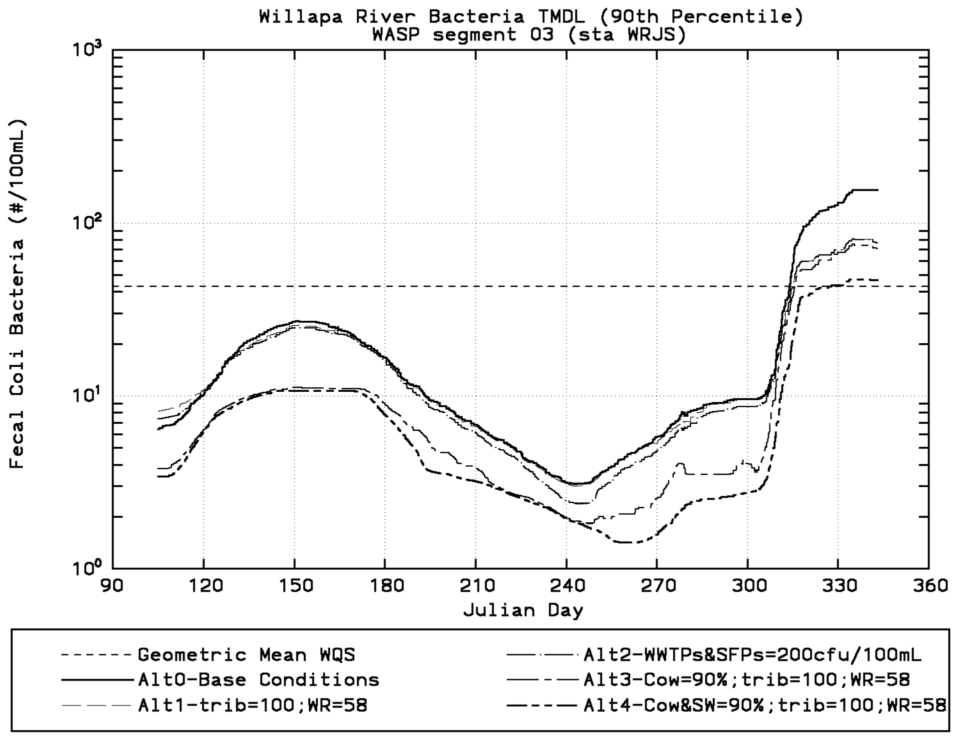

Figure B-12a. Willapa River TMDL allocations, 90th percentile at station WRJS.

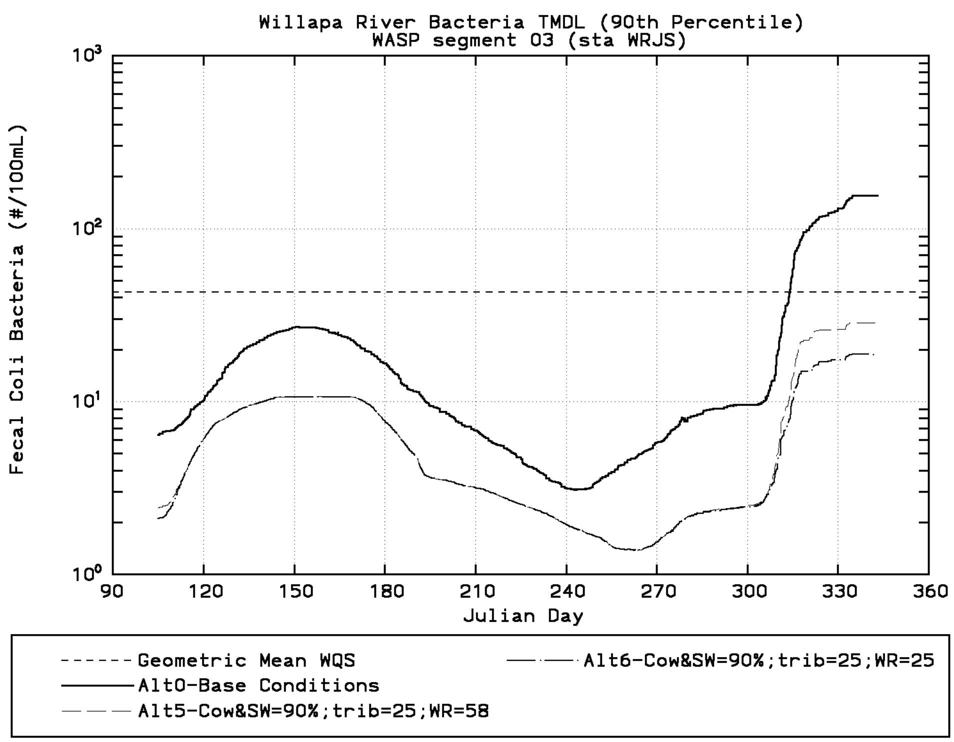

Figure B-12b. Willapa River TMDL allocations, 90th percentile at station WRJS.

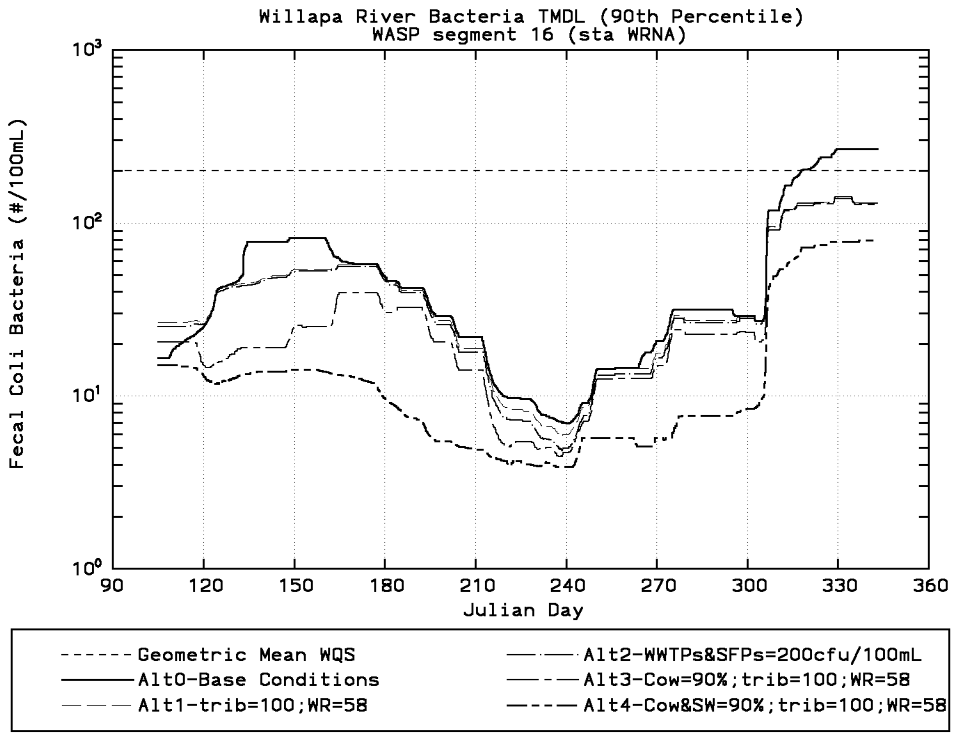

Figure B-13a. Willapa River TMDL allocations, 90th percentile at station WRNA.

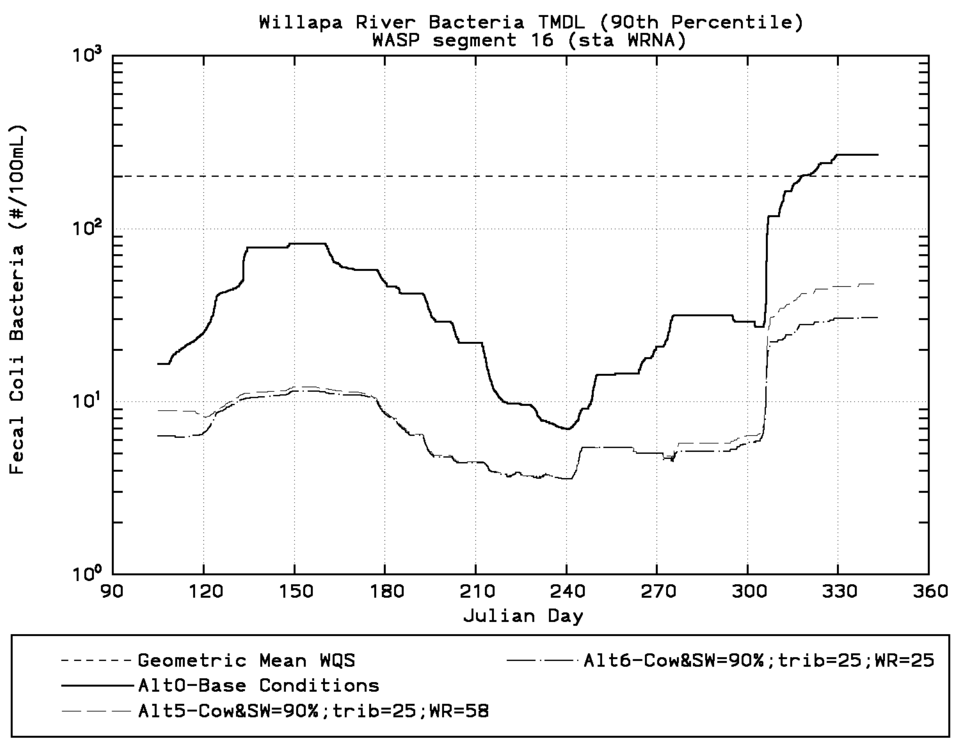

Figure B-13b. Willapa River TMDL allocations, 90th percentile at station WRNA.

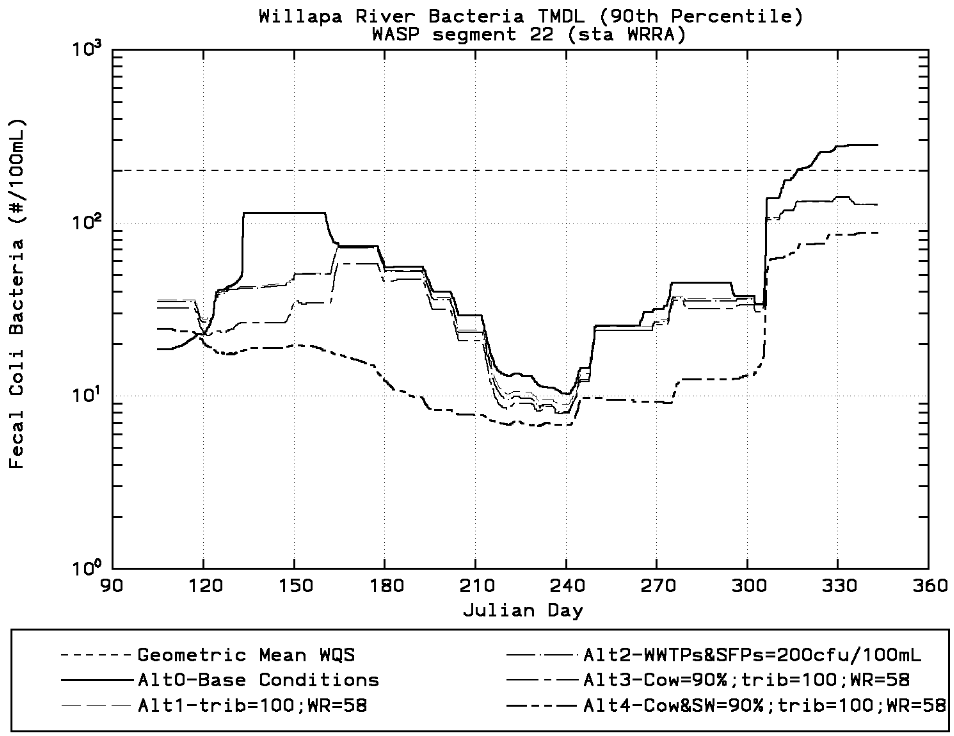

Figure B-14a. Willapa River TMDL allocations, 90th percentile at station WRRA.

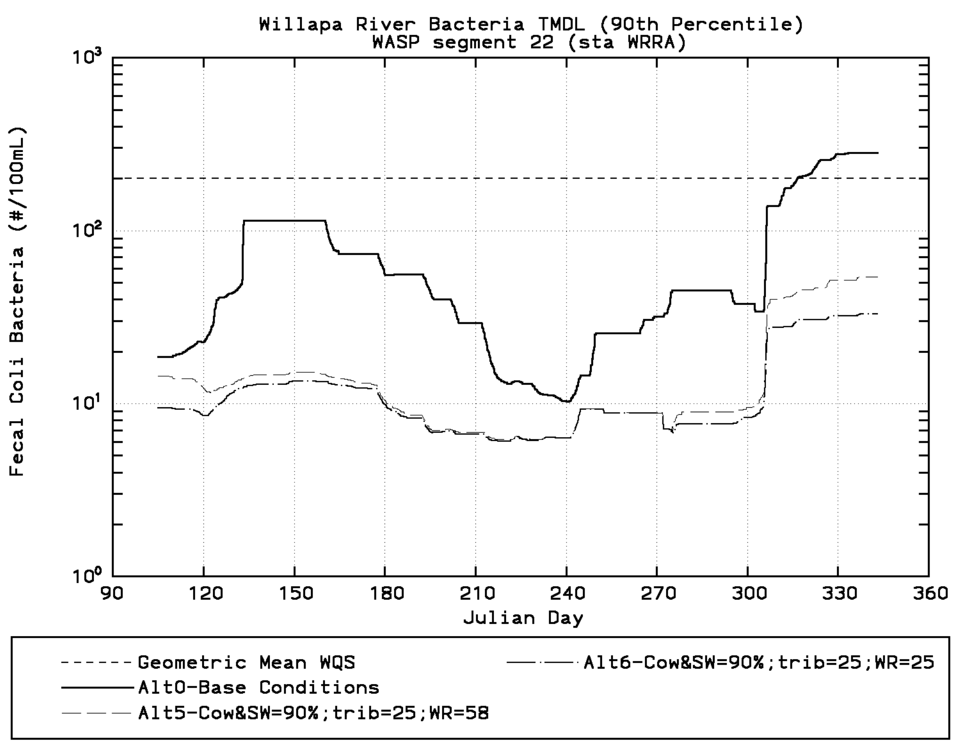

Figure B-14b. Willapa River TMDL allocations, 90th percentile at station WRRA.

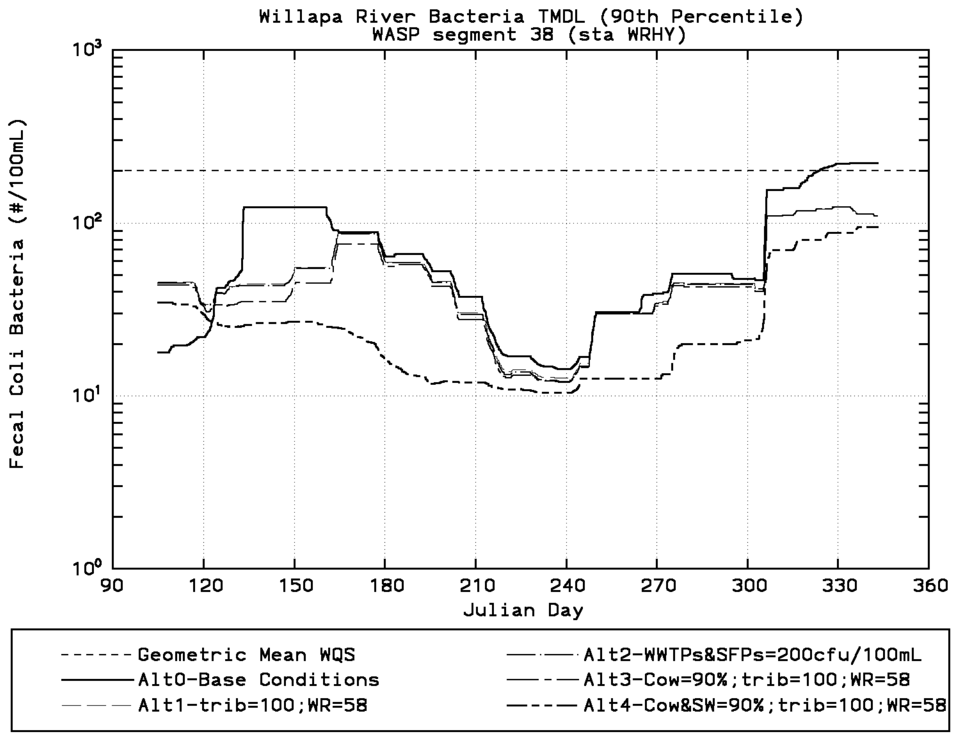

Figure B-15a. Willapa River TMDL allocations, 90th percentile at station WRHY.

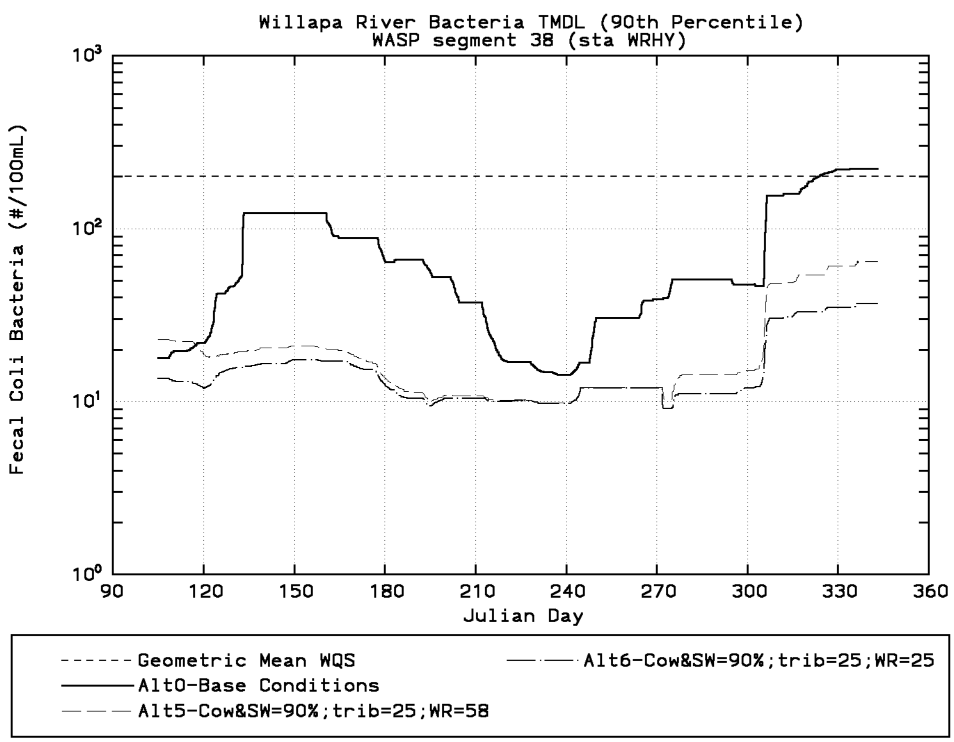

Figure B-15b. Willapa River TMDL allocations, 90th percentile at station WRHY.

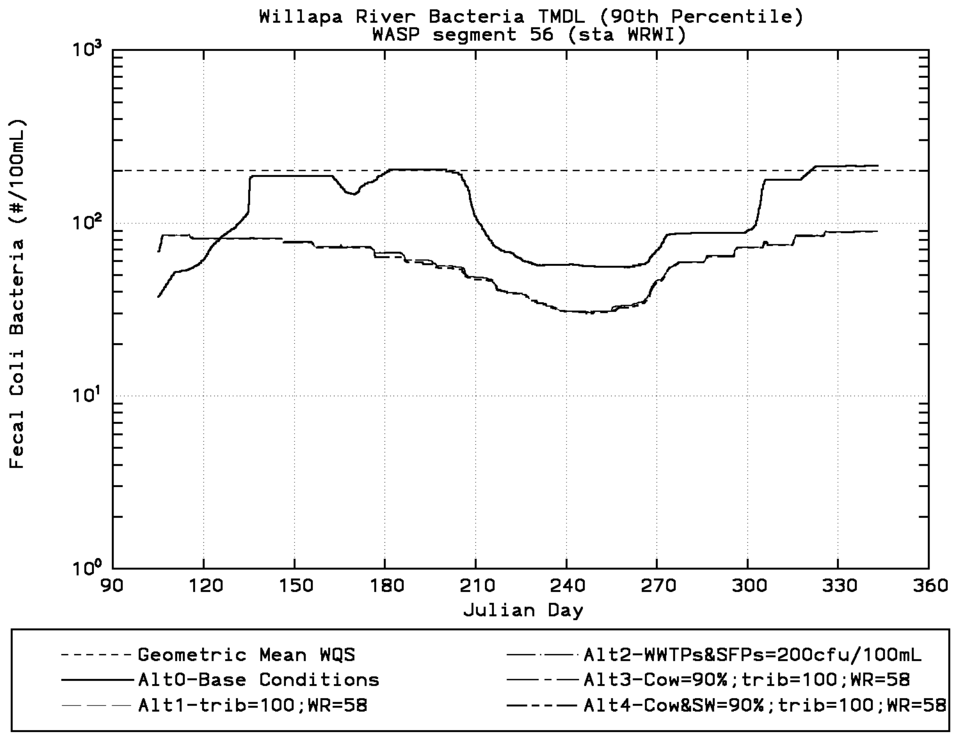

Figure B-16a. Willapa River TMDL allocations, 90th percentile at station WRWI.

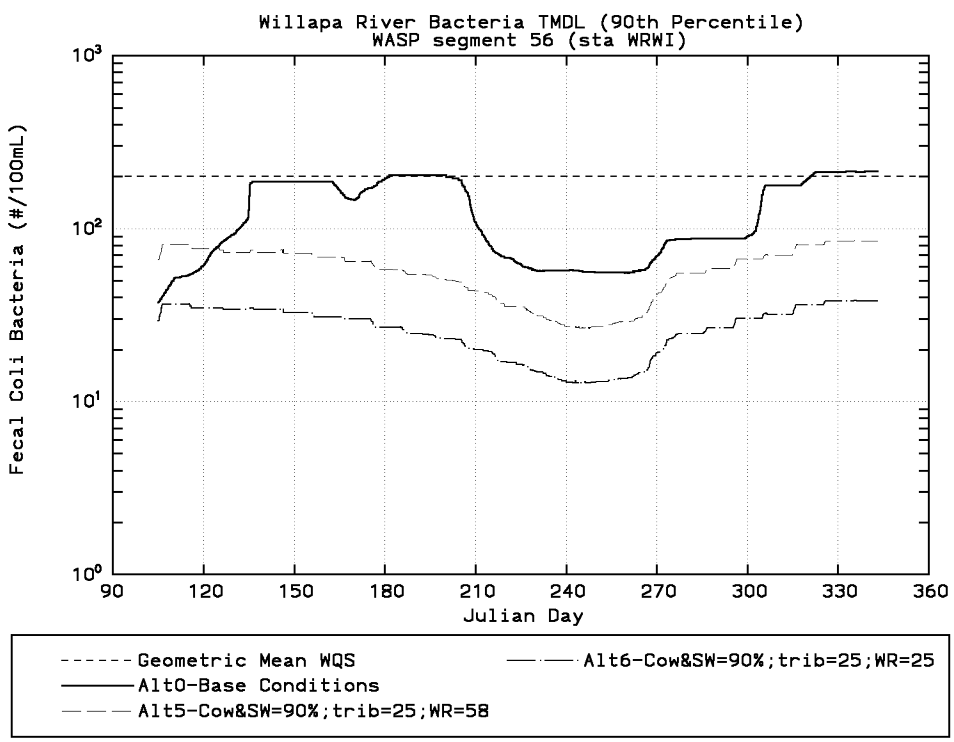

Figure B-16b. Willapa River TMDL allocations, 90th percentile at station WRWI.

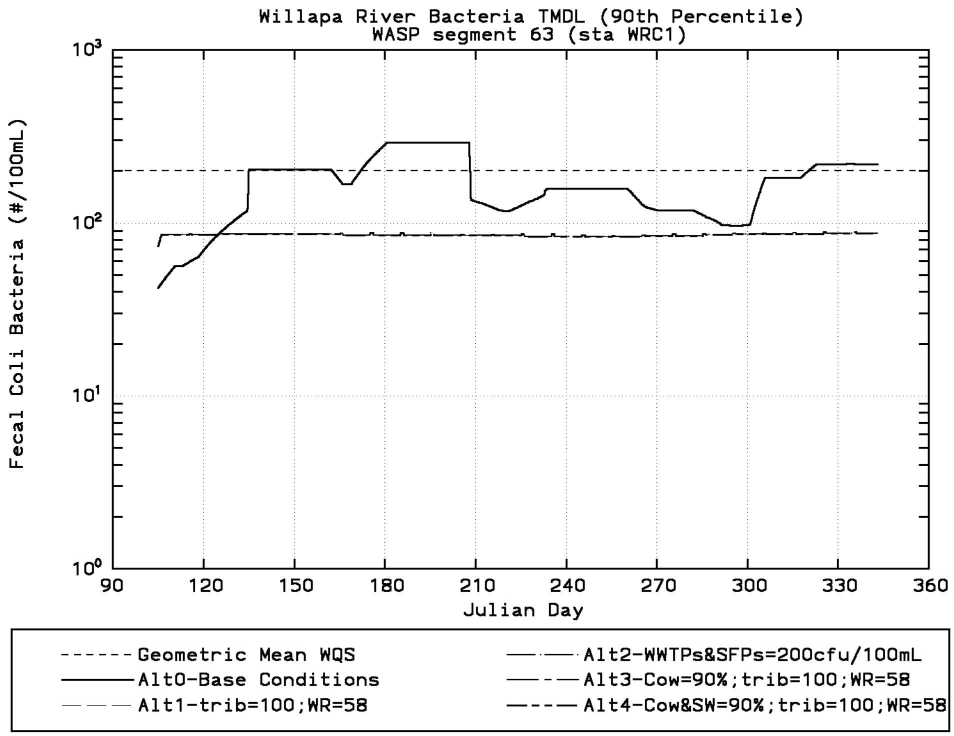

Figure B-17a. Willapa River TMDL allocations, 90th percentile at station WRC1.

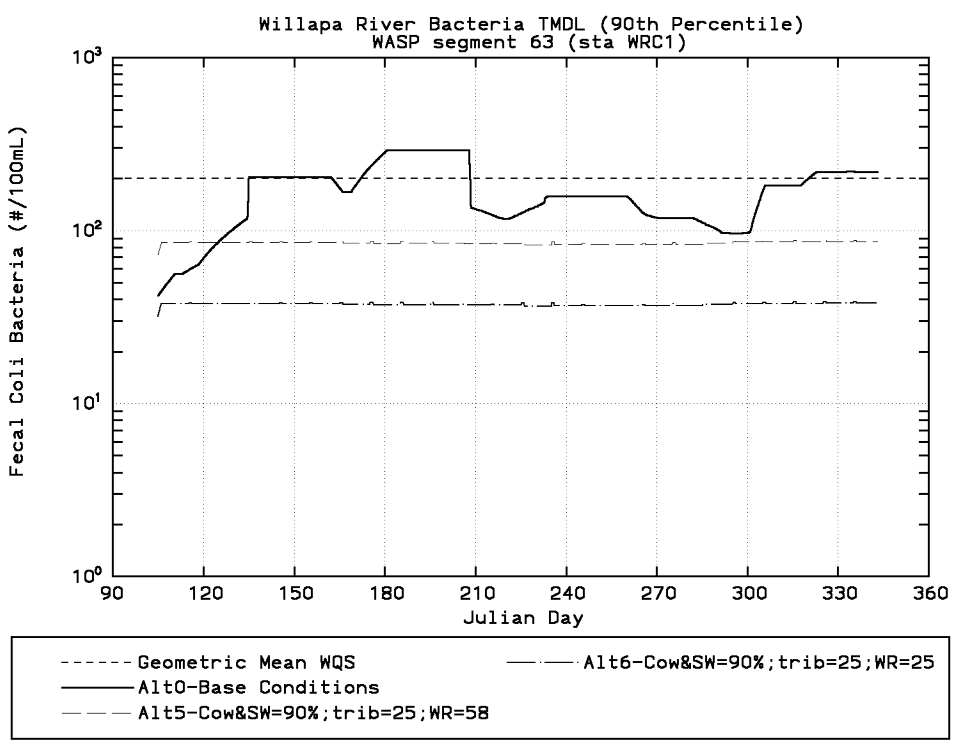

Figure B-17b. Willapa River TMDL allocations, 90th percentile at station WRC1.

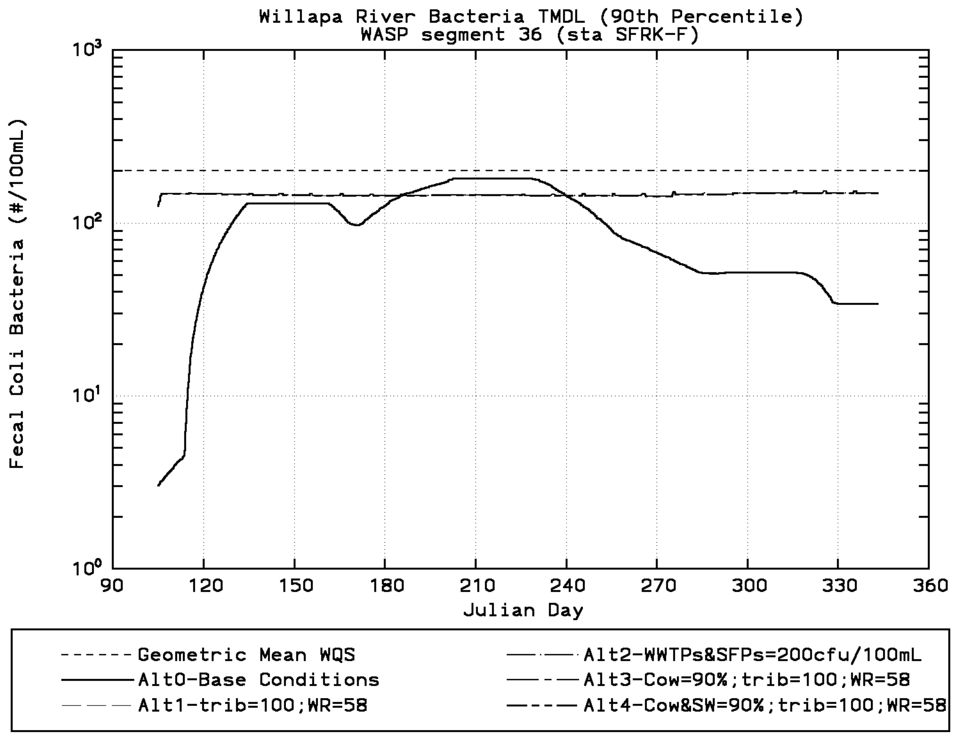

Figure B-18a. Willapa River TMDL allocations, 90th percentile at station SFRK-F.

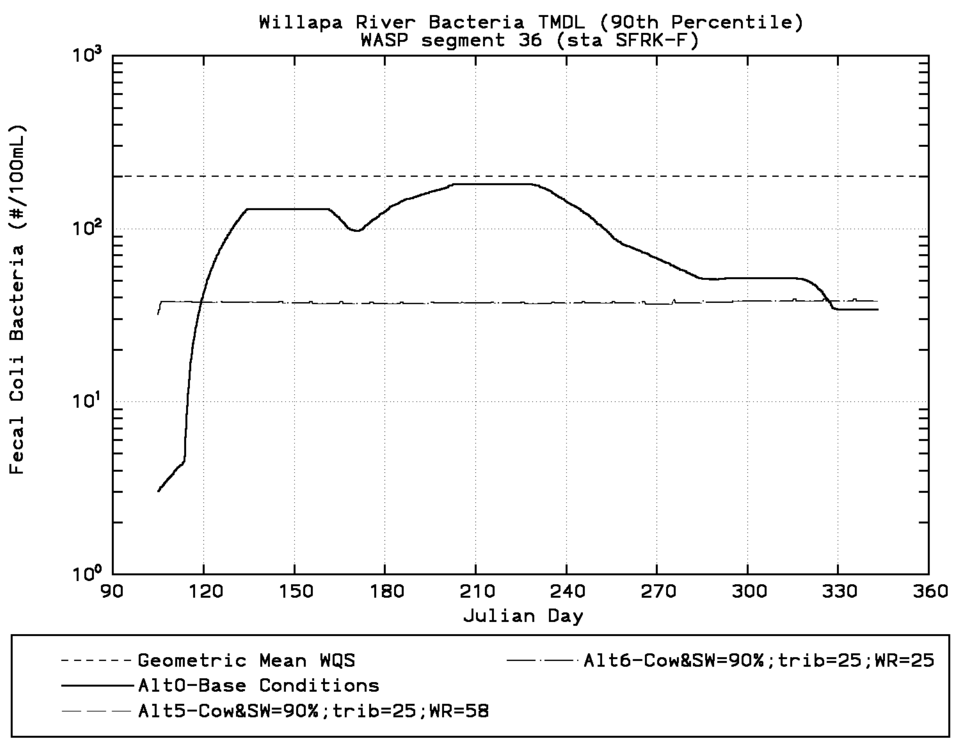

Figure B-18b. Willapa River TMDL allocations, 90th percentile at station SFRK-F.